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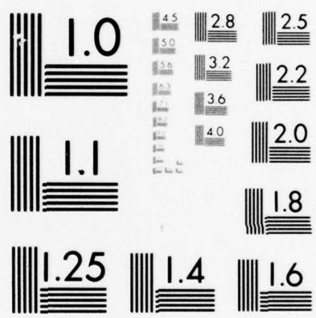
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DREDGE DISPOSAL STUDY

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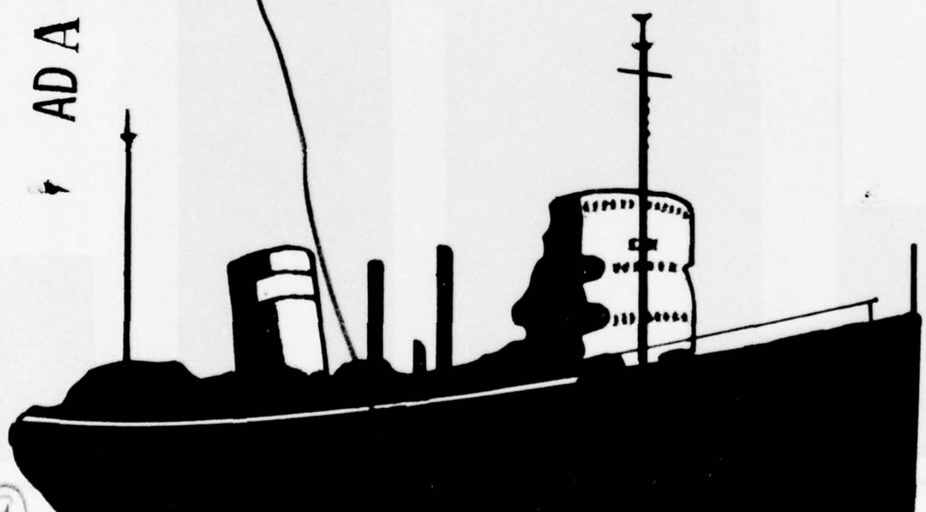
SAN FRANCISCO BAY AND ESTUARY.



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APPENDIX A.

MAIN SHIP CHANNEL
(San Francisco Bar).

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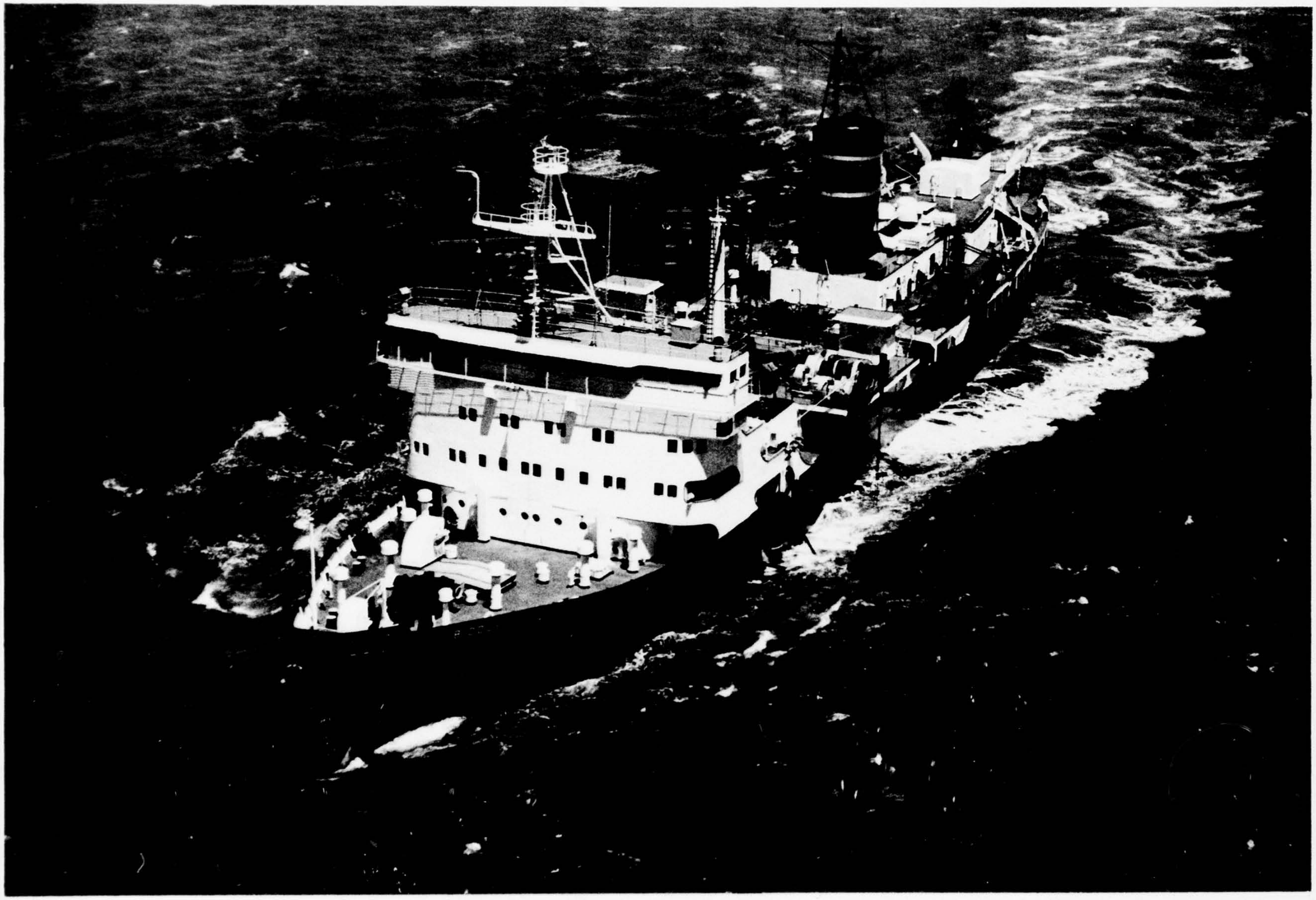

U.S. Hopper Dredge BIDDLE

DREDGE DISPOSAL STUDY
SAN FRANCISCO BAY AND ESTUARY
MAIN SHIP CHANNEL
(SAN FRANCISCO BAR)

APPENDIX A

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CONVERSION FACTORS

The measurements cited in this report include units from the British system as well as from the Metric system. All measurements are given in the units originally employed by the investigators, as any attempt to convert the expressions into a standard unit of measurement would in some cases introduce a misleading appearance of accuracy if fractional parts of the unit were employed, and in other cases would introduce large errors if the fractions were ignored.

If conversion from one system to the other is necessary, the following factors apply:

LENGTH

1 kilometer (km)=10^3 meters=0.621 statute miles=0.540 nautical miles
1 meter (m)=10^2 centimeters=39.4 inches=3.28 feet=1.09 yards=0.547 fathoms
1 centimeter (cm)=10 millimeters (mm)=0.394 inches=10^4 microns (μ)
1 micron (μ)=10^{-3} millimeters=0.000394 inches

AREA

1 square centimeter (cm^2)=0.155 square inches
1 square meter (m^2)=10.7 square feet
1 square kilometer (km^2)=0.386 square statute miles=0.292 square nautical miles

VOLUME

1 cubic kilometer (km^3)=10^9 cubic meters=10^{15} cubic centimeters =0.24 cubic statute miles
1 cubic meter (m^3)=10^6 cubic centimeters=10^3 liters=35.3 cubic feet =264 U.S. gallons=1.308 cubic yards
1 liter=10^3 cubic centimeters=1.06 quarts=0.264 U.S. gallons
1 cubic centimeter (cm^3)=0.061 cubic inches

MASS

1 metric ton=10^6grams=2,205 pounds
1 kilogram (kg)=10^3 grams=2.205 pounds
1 gr (g)=0.035 ounce

SPEED

1 knot (nautical mile per hour)=1.15 statute miles per hour=0.51 meter per second
1 meter per second (m/sec)=2.24 statute miles per hour=1.94 knots
1 centimeter per second (cm/sec)=1.97 feet per second

TEMPERATURE

Conversion Formulas $^{o}C = \frac{^{o}F-32}{1.8}$ $\qquad$ $^{o}F = 1.8(^{o}C) + 32$

DREDGE DISPOSAL STUDY
SAN FRANCISCO BAY AND ESTUARY
MAIN SHIP CHANNEL
(SAN FRANCISCO BAR)

APPENDIX A

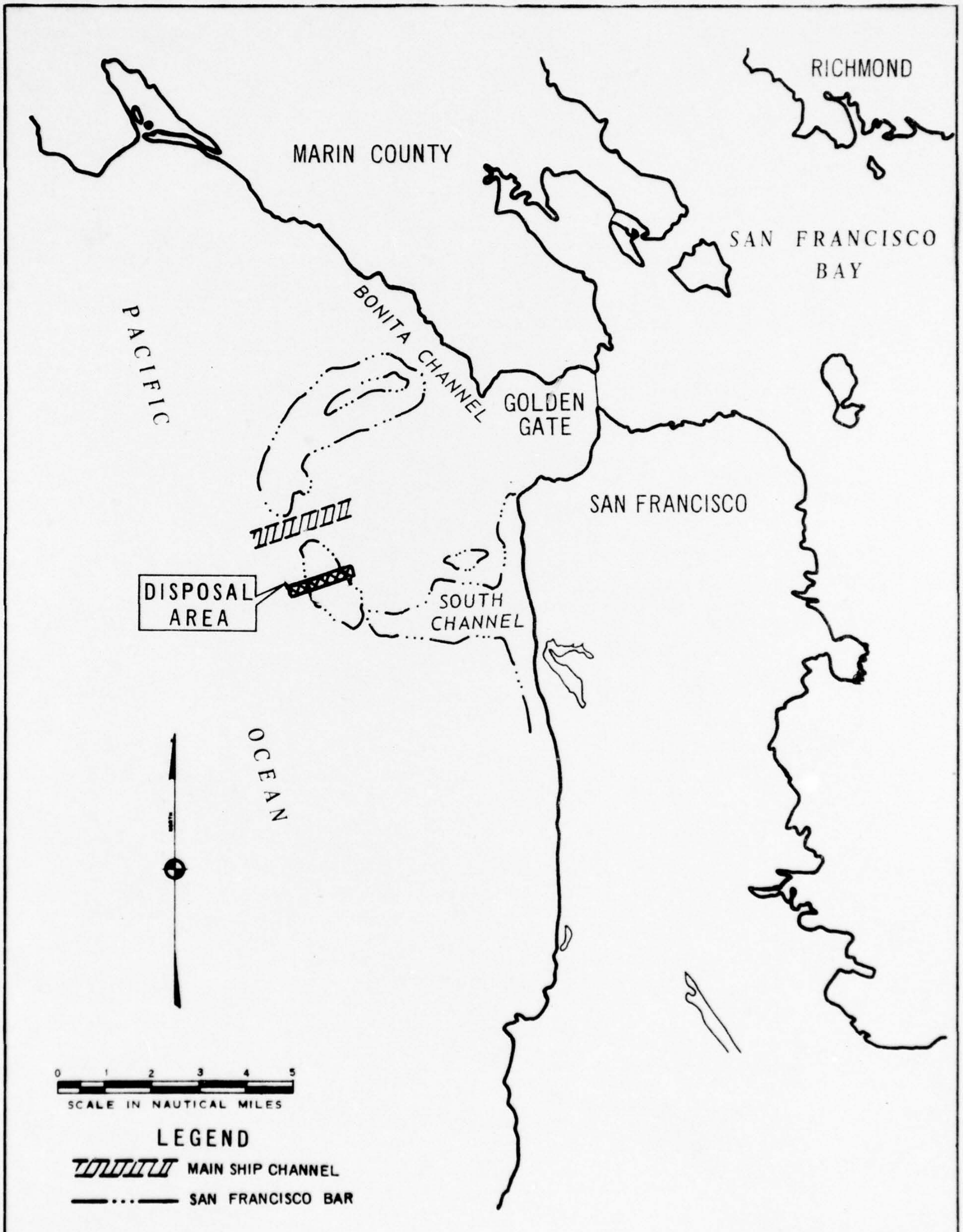
INTRODUCTION

The U.S. Army Engineer District, San Francisco is conducting a study to determine the effects of dredge material disposal on the marine environment of San Francisco Bay and Estuary. This report on the Main Ship Channel across the San Francisco Bar, Figure 1, presents the results of studies conducted on the San Francisco Bar during the period December 1970 through April 1972. This report supersedes the preliminary report, dated June 1971.

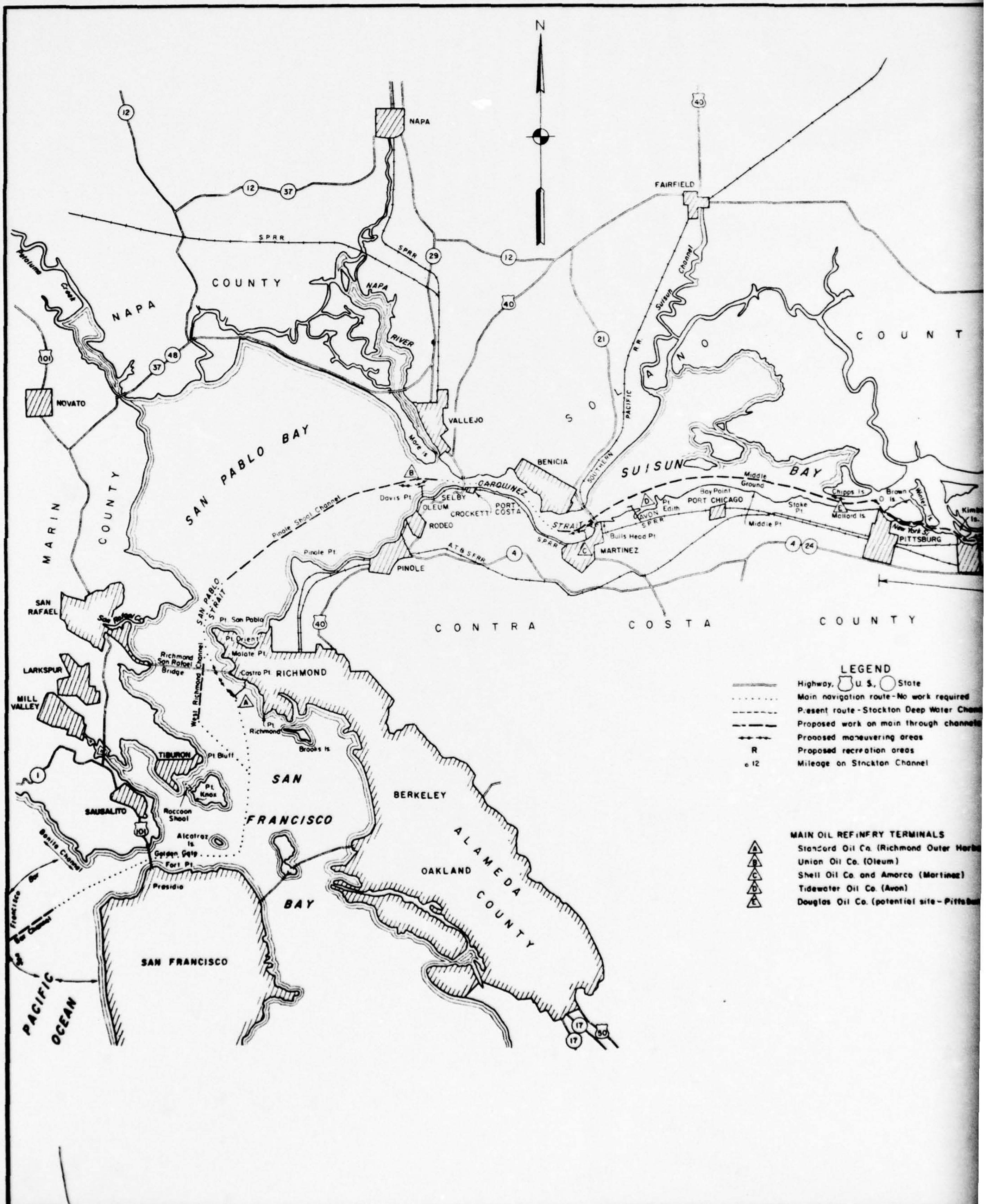
The study program included sampling, testing and analyzing the physical, biological and chemical properties of the Main Ship Channel and disposal sites on the Bar and the determination of the material dispersion and deposition pattern during the release operations.

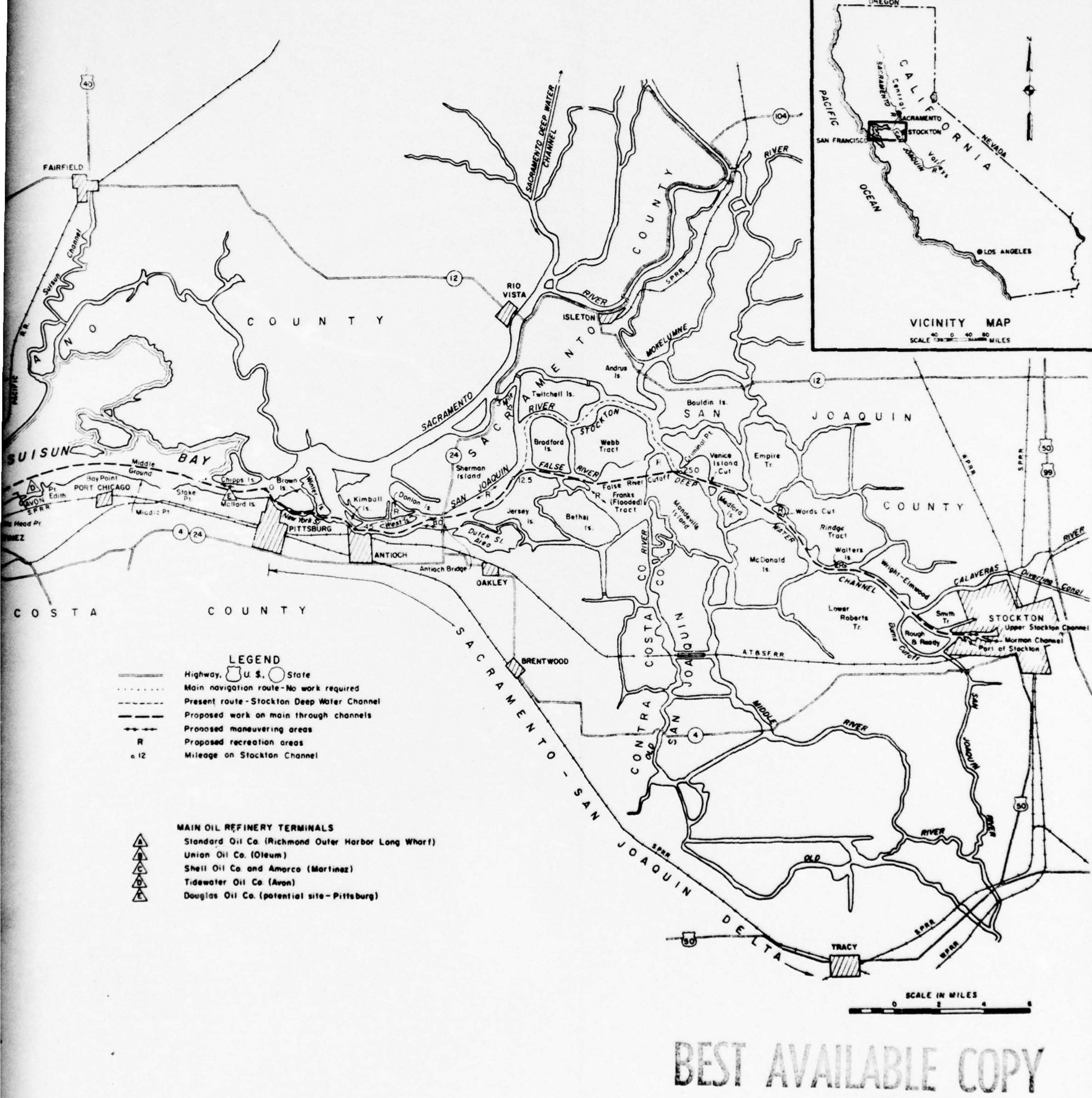
Dredging of the Main Ship Channel was performed under the John F. Baldwin and Stockton Ship Channel Project which was authorized by the River and Harbor Act of 1965. The project includes the modification of the existing San Francisco Harbor, Richmond Harbor, San Pablo Bay and Mare Island Strait, Suisun Bay Channel and San Joaquin Navigation Projects to provide depths of -55 feet mean lower low water (MLLW) for the Main Ship Channel, -45 feet for the main internal Bay channels upstream to the vicinity of Pt. Edith and -35 feet from Pt. Edith to Stockton. Also, it includes the enlargement and deepening to -45 feet of the maneuvering areas adjacent to major petroleum refinery terminals along the channel route, widening the Suisun Bay Channel, providing access and turning facilities for a potential harbor in the vicinity of Antioch, and constructing a cutoff route to Stockton through False River and certain Delta tracts (Figure 2).

In 1969, Congress enacted the National Environmental Policy Act which requires a detailed environmental impact statement on all proposals for legislation affecting the quality of human environment. The Environmental Impact Statement for the Main Ship Channel, together with comments from the Environmental Protection Agency, the U.S. Fish and Wildlife Service and the California State Resources Agency, was published in March 1971. In general, this statement indicated that based on studies available at that time, effects of dredging and material disposal on water qualities were expected to be minimal and that pollution characteristics of the disturbed materials fell within limits of the then current guidelines of the Environmental Protection Agency.



MAIN SHIP CHANNEL


N
NAPA
FAIRFIELD
SPRR
NAPA COUNTY
Petaluma Creek
NAPA RIVER
NOVATO
VALLEJO
SAN PABLO BAY
SOLANO COUNTY
BENICIA
SUISUN BAY
Suisun Channel
Pacific RR
Southern Pacific RR
CARQUINEZ STRAIT
Davis Pt
SELBY
OLEUM
CROCKETT
PORT COSTA
RODEO
PINOLE
Pinole Pt
Pinole Shoal Channel
ATB SFRR
MARTINEZ
Bulls Head Pt
AVON
Pt Edith
Bay Point
PORT CHICAGO
Middle Ground
Stake Pt
Middle Pt
Chipps Is.
Mallard Is.
Brown Is.
New York Sl.
PITTSBURG
MARIN COUNTY
SAN RAFAEL
San Rafael Cr.
SAN PABLO STRAIT
Pt San Pablo
Pt Orient
Molate Pt
Castro Pt
RICHMOND
Richmond San Rafael Bridge
West Richmond Channel
LARKSPUR
MILL VALLEY
TIBURON
Pt Bluff
Pt Richmond
Brooks Is.
Pt Knox
Raccoon Shoal
SAUSALITO
Alcatraz Is.
Golden Gate
Fort Pt
Presidio
Bonita Channel
San Francisco Bar
Bar Channel
SAN FRANCISCO BAY
SAN FRANCISCO
PACIFIC OCEAN
BERKELEY
OAKLAND
ALAMEDA COUNTY
CONTRA COSTA COUNTY
LEGEND
Highway, U. S., State
Main navigation route - No work required
Present route - Stockton Deep Water Channel
Proposed work on main through channels
Proposed maneuvering areas
R Proposed recreation areas
12 Mileage on Stockton Channel
MAIN OIL REFINERY TERMINALS
A Standard Oil Co. (Richmond Outer Harbor
B Union Oil Co. (Oleum)
C Shell Oil Co. and Amorco (Martinez)
D Tidewater Oil Co. (Avon)
E Douglas Oil Co. (potential site - Pittsburg



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SAN FRANCISCO BAY
TO STOCKTON PROJECT
GENERAL MAP

FIGURE 2

In October 1970, the President's Council on Environmental Quality (created by the National Environmental Policy Act of 1969) published a report entitled, "Ocean Dumping: A National Policy." The report discusses trends in ocean dumping, ocean pollution, alternatives to ocean dumping, and makes recommendations on legislative control of ocean dumping and international aspects of ocean disposal. With regard to ocean dumping of dredge materials, the report recommends that "ocean dumping of polluted dredge spoils should be phased out as soon as alternatives can be employed. In the interim, dumping should minimize ecological damage. Ocean dumping of unpolluted dredge spoils......which are inert and non-toxic should be regulated to prevent damage to estuarine and coastal areas."

PURPOSE OF STUDY

The purpose of the Dredge Disposal Study, as applied to the Main Ship Channel, is to determine the effects of dredging and material disposal on the San Francisco Bar environment and to develop dredging procedures and disposal sites to mitigate possible adverse effects on and/or enhance the marine resources of the affected areas.

DESCRIPTION OF SAN FRANCISCO BAR AND MAIN SHIP CHANNEL

The San Francisco Bar, shown on Figure 1, extends in an arc about 5 miles west of the Golden Gate. The Bar is separated from the mainland by Bonita Channel on the north. Depths across the Bar vary from -24 feet MLLW or less on the northern portion known as the Four-fathom Bank or Potatopatch to about -36 feet MLLW on the remainder of the Bar. The width of the Bar varies from about one to two miles. The Main Ship Channel had previously been maintained to the 1935 authorized depth and width of -50 and 2,000 feet, respectively. Prior authorized depths were -40 feet in 1921 and -45 feet in 1930. The channel is subject to maintenance dredging on the order of 600,000 cubic yards per year. Pre-dredging depth of the Bar at the location of the ship channel was about -32 feet MLLW.

Previous studies of San Francisco Bar have been conducted by Gilbert (Ref. 1) early in the century and by Grimm in 1931 (Ref. 2). A plot of the hydrodynamics on the Bar from the 1931 study is included as Inclosure 1. The Bar is in approximate dynamic equilibrium due to the prevailing wave action which tends to move sediment eastward, tidal currents occurring during ebb flows from San Francisco Bay which move sediment westward and coastal currents. Very little information is available to further define this equilibrium.

Median grain size studies have been made by Professor Byron Schatz of the University of California, Berkeley (Ref. 3). Median grain size of bottom surface material range from 0.6 mm at a depth

of 90 feet outside the Golden Gate to 0.2 mm on the top of the Bar. Median grain sizes of samples obtained in the channel from previous dredging operations have decreased from 0.22 mm in 1956 to 0.16 mm in 1962 and 0.14 mm in 1970. Three conflicting theories on the formation and continuance of San Francisco Bar have met with varying amounts of acceptance. The three theories differ mainly in the postulated source and placement of Bar material and not with the forces keeping the Bar in approximate dynamic equilibrium. The first theory postulates that the Bar was formed entirely from material originating from upcoast erosion and sediment discharges from local streams. These sediments were moved downcoast by prevailing southerly longshore transportion. When the material encountered the deep waters at the entrance to the Golden Gate and the strong ebb currents it was moved offshore and deposited at a depth too deep for the material to be moved by wave action and at a location outside the Golden Gate where the ebb tidal current velocities were insufficient to carry the material any further seaward. Deposition of the sediment continued until the depth was such that the material being moved in the littoral regime could bypass the Golden Gate and continue in transit downcoast. The accumulation of the southerly moving sediment represents the bar, the depth and location of which depends on the strength of the ebb tidal currents, the prevailing westerly wave action and the supply of sediment from upcoast. The second theory postulates that the Bar was formed entirely from sediments within the San Francisco Bay. In this case the coarser materials emitted from the Bay were deposited in an arc around the entrance to the Golden Gate as a result of the decreasing hydraulic energy gradient from the ebb tidal prism as it moves out of the Bay. The finer material was carried out over the Bar and deposited in deeper water. This theory accounts for the decreasing grain size distribution across the Bar. The third theory postulates that during the lowering of sea level during the Wisconsin Ice Age, the Sacramento-San Joaquin River System discharged its sediment load directly onto the continental shelf outside the Golden Gate. During the lower stand in sea level, massive accumulations of alluvial sands were deposited outside the entrance to the Golden Gate. During the inter-glacials with rising sea level, these sand deposits were redistributed to form the present configuration of the Bar. As sea level rose, the tidal prism of San Francisco Bay increased, thus, progressively shifting the Bar seaward until now it has reached its present location. In the past as sea level rose and fell the position of the Bar shifted seaward and landward and during periods of very low stands in sea level the Bar would actually be destroyed.

Historical movement of the Bar from 1855 to 1957 has been generally landward. However, as noted in the Technical Report on Barriers (Ref. 4) significant shifts have occurred seaward during major floods on the Bay tributaries, indicating a sensitive equilibrium which is dependent on the tidal prism of the Bay. The tidal

prism for an average tidal range of 4-1/4 feet at the Golden Gate is about 1.2 million acre-feet (390 billion gallons). The prism for extreme ranges is estimated to be about 2.7 million acre-feet. Tides at San Francisco are semi-diurnal. During the summer, prevailing winds and swells are from the northwest with some distant storms from the southwest. In addition to this, the California coast exhibits three distinct oceanographic seasons. They are the Upwelling occurring in spring with an overturning of the upper layers from moderate depths, Oceanic in fall with a southward movement of both surface and deep currents, and Davidson in winter with northward surface currents near shore (Refs. 5 and 6).

Littoral transport of sand along the coast of northern California is generally directed southward. Street, Mogel and Perry (Ref. 7) in their littoral transport studies along the shores of San Francisco, using automatic data processing methods, found a sizable breaker zone along the crest of the San Francisco Bar indicating that transportation phenomena exist along the crest of the Bar. Further, tracer studies by Kamel (Ref. 8) found local maximum concentrations of radioactive thorium and heavy minerals on the crest of the Bar and at San Francisco Beach, thereafter decreasing to the south also indicating that transportation phenomena exist on the Bar and that it is directed south.

DREDGING QUANTITIES AND CONSTRUCTION SCHEDULE

Based on sounding surveys made in January and February 1971, estimated material removal from the Main Ship Channel to establish project depth of -55 feet MLLW was about 4.1 million cubic yards, including 2.2 million cubic yards of authorized overdepth.

Excavation is accomplished by the U.S. Hopper Dredge BIDDLE. Based on past experience involving weather and sea conditions, dredging and disposal time, and contingency factors, total construction time of about 5.3 months was estimated for the new work dredging. The total dredging time was spread over a period of about three years. This interval was necessary because the BIDDLE, the only West Coast based hopper dredge capable of performing the dredging work on the Main Ship Channel, also performs scheduled maintenance for other West Coast ports. New construction dredging included about 1 month in June 1971, 1 month in January-February 1972, 1.3 months in January-February 1973 and 2.3 months in December 1973-February 1974. Increasing the depth of the channel from -50 to -55 feet is expected to increase the annual maintenance dredging by 360,000 cubic yards to 960,000 cubic yards.

DREDGE DISPOSAL SITES

The past procedure for dredge material disposal had been to waste the material in deep water outside the Bar about one mile southwest of the channel entrance. Disposal in deep water prevents the

material, a native sand of the Bar, from reentering the littoral regime, resulting in the loss of the sand as a natural resource. Dr. Hans Einstein of the University of California, Berkeley, serving as a consultant for the San Francisco District, Corps of Engineers, suggested that dispersion of the material on the Bar south of the channel would retain the material in the littoral regime with the possible effect of nourishing the coastline to the south. His preliminary opinion is that of the three basic possibilities for material disposal - on land, in deep water and on some part of the Bar, the latter appears to be the most desirable. His remarks, in part, are as follows:

"When it comes to the assessment of the ecological effects of dredging the bar channel for maintenance of the shipping channel, one must first remember that the bar is comparable with the permanently submerged part of a beach on which the beach material is continuously shifting at a considerable rate. No form of life is possible there which depends on continuous contact with the free water without being able to move itself freely to find the needed contact with the free water. Most such forms of life must be expected to suffer very little by the process of being dredged together with the sediment. The dredging process at the bar itself should not interfere drastically with any form of life."

"After removal of the sediment and possibly such forms of life as may sustain themselves on the bar the question arises which may be the best choice for the location of redeposit of the dredged material. There are basically there possibilities:

On dry land.

In some deepwater location where it will not return to the shipping channel.

On some other part of the beach-bar system."

"Deposition in the dry is desirable in all those cases where the dredged material must be preserved from redeposition in the same location from which it is dredged in the first place. The danger exists in these cases where the natural system of sediment motion in the area is not known and, therefore, cannot be predicted. Along a beach with a distinct and predictable longshore sediment motion this condition is not fulfilled and total removal of the sediment and any possible forms of life in it is not indicated for this reason. Total removal of the material may even by very disadvantageous. Let us assume that it is established that there exists a considerable net transport of sediment from the north to the south. All the sediment permanently removed from the bar would not be able to reach the beaches to the south and the beaches would be starved of sediment and start to retreat which is definitely undesirable and should be prevented. The first possibility may thus be rejected."

"The second possibility of deposition in deep water may use either an area inside the bar or outside the bar. If a location between the bar and the Golden Gate is chosen one must assume that there, the tidal currents must be sufficiently strong to move the sand back to the bar and the ship channel, because otherwise the bar would have formed in that location. This solution appears to be undesirable. If a location of deep water outside the bar is chosen from where the sediment cannot return to the bar, one incurs all the disadvantageous of the first solution and in addition runs the risk of gravely disturbing the existing ecosystem at location of deposition by addition of the incompatible dredge material. This solution must also be rejected, possibly even more strongly than the first one."

"The third solution attempts to deposit the sediment which had accumulated in the shipping channel along the bar where it would have moved by the waves and currents if the channel had not been dredged in the first place. Due to the presence of the channel some of the bar sediment is continuously being scoured from the crest of the bar, most near the channel and increasingly less as one moves away from the channel. The distribution along the bar crest of the scour depends to a large part on the past hydrology, i.e., on the temporal distribution of the sediment motion in the two directions. It appears to be unnecessary to distribute the dredge spoil exactly according to the distribution of the scour since the last dredging since the natural forces redistribute the material rather effectively. It is important, on the other hand, to remove the deposits sufficiently far from the channel to prevent significant amounts from being washed back into the channel by possible periods of reverse motion."

Professor Einstein also recommended further studies to arrive at a more complete understanding of sediment movement on the Bar to determine the best possible location and distribution of the disposal area.

The desirability of placing the sandy dredge material within the littoral drift regime is further supported by Professor Raymond F. McAllister, Professor of Ocean Engineering, Florida Atlantic University, in a letter dated 26 February 1971, to Governor Ronald Reagan in which he cited similar experience in Florida where deepwater disposal of sandy material has aggravated the beach erosion problem by depriving the beaches of this nourishment material.

Acting upon the recommendation of Dr. Einstein, the San Francisco District now disperses dredged material from the Main Ship Channel on the San Francisco Bar south of the channel. During the initial new constrution dredging in June 1971, the material was dispersed a minimum of 3,000 feet south of the channel. The minimum distance was increased to 6,000 feet during the maintenance dredging and the new construction dredging during January-March 1972. The increase in minimum distance will reduce the probability of material reentering the channel, especially during the winter Davidson oceanographic season when nearshore currents trend northerly.

DREDGE OPERATION

The Bar dredging operation is done by the Hopper Dredge BIDDLE, pictured in the frontispiece. The BIDDLE, a side-drag hopper dredge built in 1947, is the largest of the hopper dredges assigned to the Portland District, Corps of Engineers. The overall length is 351 feet and 8-3/4 inches with a beam of 60 feet. Maximum and minimum dredging depths are 70 and 22 feet, respectively. Top speed is 14.8 statute miles per hour and personnel complement is 15 officers and 77 men. Dredging is accomplished with two 1,150 horsepower pumps. The suction line is 30 inches and the discharge line is 28 inches in diameter. Hopper capacity is 3,060 cubic yards. Added equipment, however, has reduced the actual operating capacity to about 2,900 cubic yards.

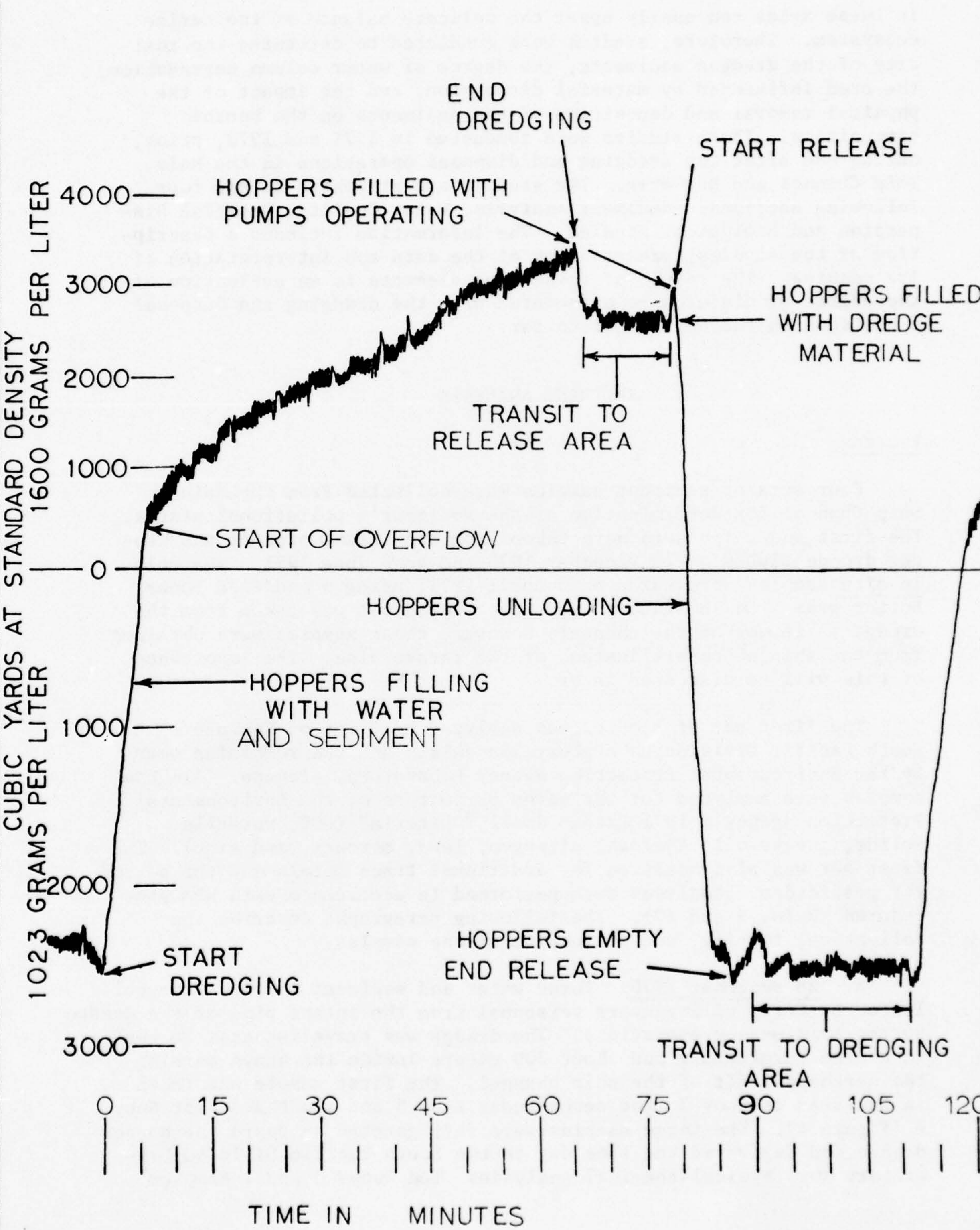
The material release area on the Bar extends the full length of the Main Ship Channel and parallel to the channel. Release of material is conducted with the vessel underway in order to accomplish the greatest dispersion in the area. Vessel speed is maintained as high as practicable, consistent with the safe and efficient operation of the dredge.

The operation of the dredge is represented on Figure 3, a typical graph of vessel displacement correlated to the hopper capacity. The graph covers one full cycle from the BIDDLE on the San Francisco Bar on 9 June 1971. For the operation on the Bar, a full cycle time ranged from about 110 to 130 minutes with loading times ranging from about 60 to 80 minutes. The plot below the zero line on the graph represents the hopper filled with water. The plot above the zero line is the volume of material in cubic yards with a standard density of 1,600 grams per liter. The horizontal scale is 5 minutes per unit. Practical limits for pumping the fine sand found on the Bar are 15 to 20 percent solids by volume at suction velocities of 15 to 20 feet per second. Actual pumping is probably about 10 percent. The suction outlet is at the rear of the hopper.

Material is released from the hopper through twelve valves in sets of two. The valves are hydraulically operated gates opening downward from the bottom of the vessel. During the release, the pumps are operated to create a viscous state and to flush the hopper. The valves are opened starting with the front set in order to maintain the stability of the vessel. The maximum speed of the release is limited by the allowable stresses on the gates, the release of material, the sea state and the bottom clearance. Jaming any one of the twelve valves would make the dredge inoperable.

STUDIES CONDUCTED

The estuarine and continental shelf areas are extremely biologically active serving as the nursery grounds and/or habitat for the majority of marine species. Man-associated environmental impacts



TYPICAL DREDING CYCLE

in these areas can easily upset the delicate balance of the marine ecosystem. Therefore, studies were conducted to determine the toxicity of the dredged sediments, the degree of water column degradation, the area influenced by material dispersion, and the impact of the physical removal and deposition of the sediments on the benthic communities. These studies were conducted in 1971 and 1972, prior, during and after the dredging and disposal operations in the Main Ship Channel and Bar area. The studies are presented in the four following sections: Sediment Analysis, Water Quality, Material Dispersion and Biological Studies. The information includes a description of the studies, presentation of the data and interpretation of its meaning. The result of these four elements is an evaluation of the degree of disturbance associated with the dredging and disposal operations on the San Francisco Bar.

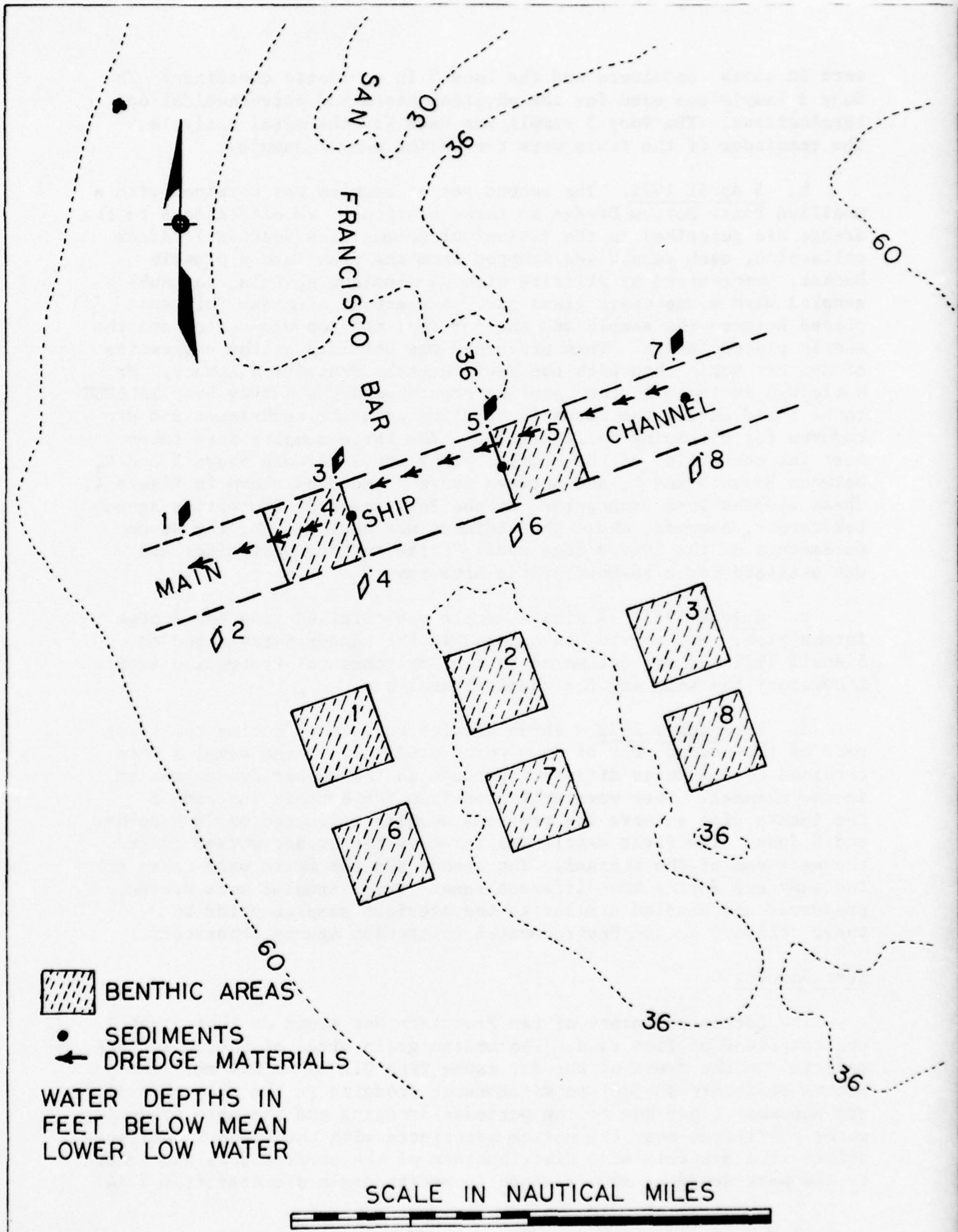
SEDIMENT ANALYSIS

Program

Four sets of sediment samples were collected from the Main Ship Channel for determination of the sediment's pollutional status. The first and third sets were taken from the intake pipe of the hopper dredge BIDDLE on 28 December 1970 and on 8 June 1971. The only *in situ* samples were taken on 5 April 1971, using a modified Ponar bottom grab. On 18 January 1972, the fourth set was taken from the dredge as it worked the channel; however, these samples were obtained from the ship's hoppers instead of the intake pipe. The importance of this will be discussed later.

The first set of samples was analyzed by Corps of Engineers South Pacific Division Laboratory, Sausalito and the remaining sets by the Environmental Protection Agency Laboratory, Alameda. All the samples were analyzed for the seven parameters of the Environmental Protection Agency's 1971 Dredge Spoil "Criteria" (COD, volatile solids, grease-oil, kjeldahl nitrogen, lead, mercury, and zinc). The first set was also analyzed for additional trace metals and the second for pesticides. Analyses were performed in accordance with EPA procedures (Refs. 9 and 10). The following paragraphs describe the collection, testing, and evaluation of the samples.

a. 28 December 1970. Three water and sediment samples were collected by Corps of Engineers personnel from the intake pipe of the dredge during maintenance operations. The dredge was traveling east to west in a line paralleling and about 200 meters inside the buoys marking the northern limit of the ship channel. The first sample was taken in the area of Buoy 3, the second near Buoy 5 and the third near Buoy 7 (Figure 4). The three samples were refrigerated on board the hopper dredge and delivered the same day to the South Pacific Division Laboratory for physical-chemical analysis. The Buoys 3 and 7 samples



SAMPLING LOCATIONS

were in glass containers and the Buoy 5 in a plastic container. The Buoy 3 sample was used for the physical tests and petrochemical determinations. The Buoy 5 sample was used for the metal analysis. The remainder of the tests were run on the Buoy 7 sample.

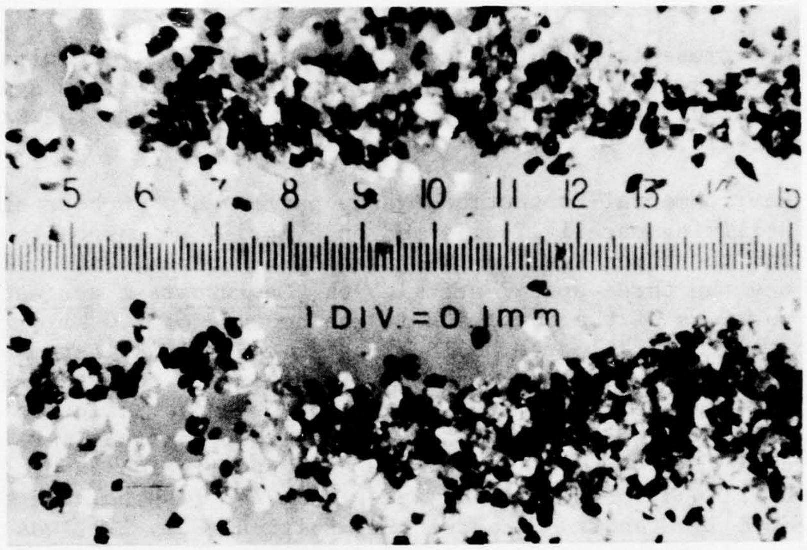
b. 5 April 1971. The second set of samples was obtained with a modified Ponar Bottom Dredge at three stations. (Modifications to the dredge are described in the Biological Communities Section.) After collection, each sample was dropped from the grab into a plastic bucket, homogenized by stirring with an aluminum spatula, and subsampled with a one-quart glass jar. A piece of aluminum foil was placed between the sample and the jar top; the top was sealed and the sample placed in ice. This procedure was utilized at the suggestion of Mr. Art Noble then with the Environmental Protection Agency. Mr. Noble was included in the sampling crew aboard the survey boat HALLECK to help and advise the Corps in adopting adequate techniques and procedures for obtaining valid samples. The three samples were taken near the centerline of the channel along lines between Buoys 3 and 4, between Buoys 5 and 6, and between Buoys 7 and 8 as shown in Figure 4. These samples were transported to the Environmental Protection Agency Laboratory, Alameda, where the sediment was analyzed for the seven parameters of the 1971 dredge spoil "Criteria" and pesticides and was utilized for a 96-hour static bioassay.

c. 8 June 1971. A single sample was obtained from the dredge intake pipe. The sample was handled in the manner established on 5 April 1971 and was delivered to the Environmental Protection Agency Laboratory the same day for chemical analysis.

d. 18 January 1972. Three samples were taken during the first part of the second year of "new work" dredging. These samples were obtained during three different periods as the hopper dredge worked in the channel. They were collected from the hoppers instead of the intake pipe as were the previous samples collected on 28 December and 8 June. The first sample was taken as the dredge worked toward the west end of the channel. The second and the third were taken at the east end during two different runs. These samples were stored, preserved and handled similar to the previous samples prior to their delivery to the Environmental Protection Agency Laboratory.

Test Results

The bottom sediments of San Francisco Bar shown on Photograph 1 are comprised of fine sand. The median grain sizes of bottom surface material on the crest of the Bar range from 0.2 mm to 0.4 mm. The bottom sediments subject to maintenance dredging in the ship channel are somewhat finer due to the periodic dredging and the more tranquil water conditions near the bottom associated with the channel configuration. The particle size distributions of the samples obtained prior to new work dredging show a range in median grain diameter from 0.14



PHOTOGRAPH 1 SEDIMENTS
SAN FRANCISCO BAR

mm to 0.18 mm. Gradation curves of samples taken on 28 December 1970 in the ship channel are shown in Figure 5. Figure 6 is gradation curves of sediments in the disposal area. Comparison of the curves shows that the particle size distributions are essentially identical for the two areas.

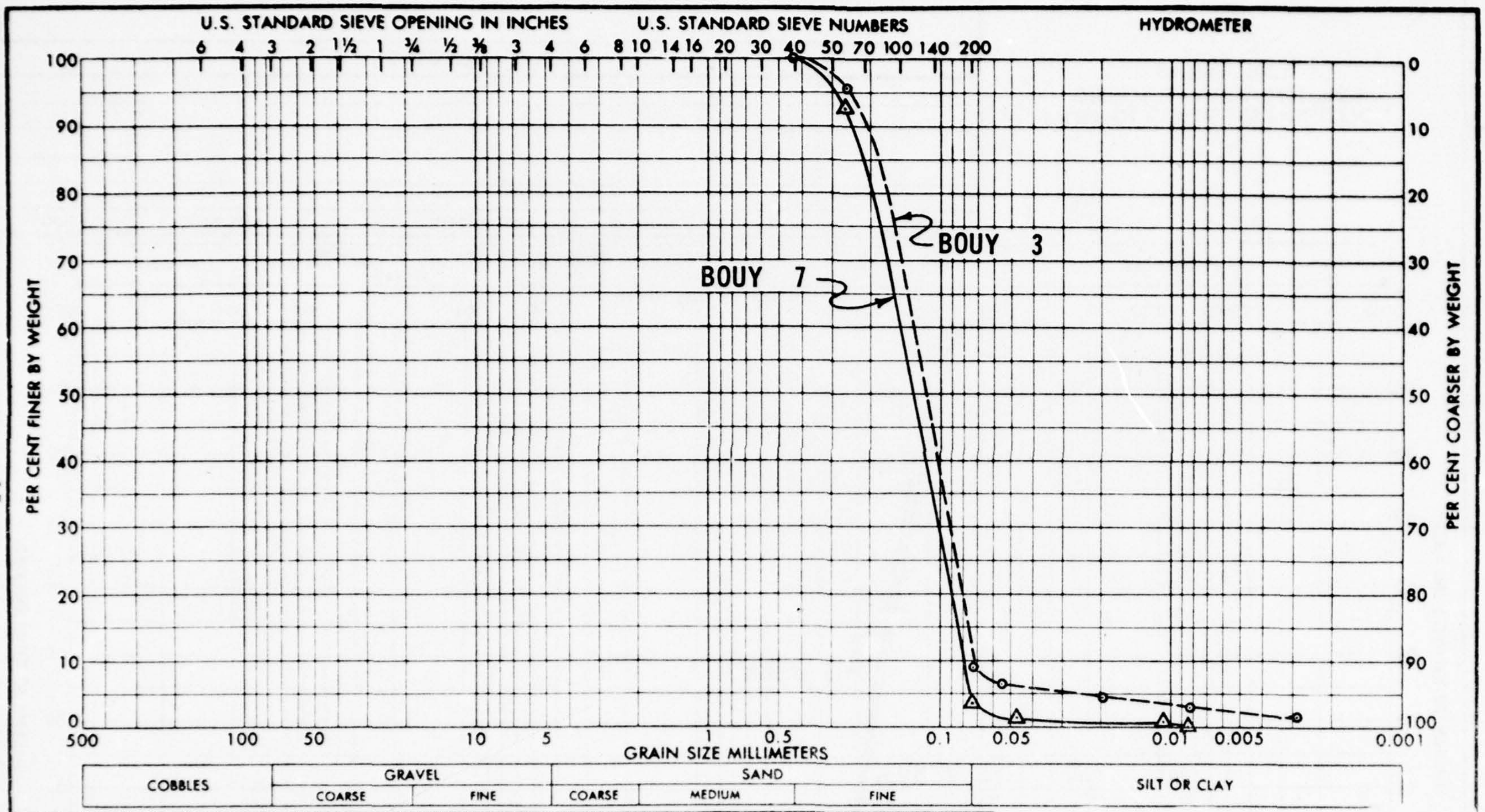
Table 1 presents a comparison of sediment analysis results and the 1971 criteria published by the Environmental Protection Agency for determining the acceptability of dredged material to the Nation's waters (Ref. 11).

The Environmental Protection Agency performed a 96-hour static bioassay utilizing material collected on 5 April. A composite of the samples from the three stations was used in the experiment. The test organism was the three-spined stickleback, *Gasterosteus aculeatus*. Weighted portions of the composite in the amounts of 1.0 kilogram, 0.56 kilogram, 0.32 kilogram, 0.18 kilogram and 0.10 kilogram were placed in 20-liter widemouth glass jars. Steinhart seawater (Steinhart Aquarium, California Academy of Science) was used for dilution and each container brought to a volume of 15 liters. Two controls were used in the experiment. Control 1 used 100 percent dilution water (Steinhart seawater) and Control 2 used water from the fish holding tank. The procedure in *Standard Methods*, 12th Edition (Ref. 12), was followed. Temperatures in the experiment ranged from 16°C. to 18.2°C. Tolerance limits were not established because of the high survival rate. Results of the bioassay are presented in Table 2. The experiment indicated the sediment was non-toxic to the sticklebacks.

Discussion

The two sets of samples collected on 28 December 1970 and 8 June 1971, which were taken from the intake pipe of the hopper dredge, differed from the 5 April *in situ* set only in the degree of homogenity. The samples taken from the Ponar dredge were homogenized after they were dumped in the plastic tub. Reasonably, the level of pollutant concentration in these first three sets of samples was nearly equivalent. The only sample significantly different from the others in its pollutant level was the second grab sample taken on 5 April. When this grab was emptied into the tub the material was noticeably finer and contained a much higher degree of organic detritus than previously collected channel sediment. This seems to indicate that the sample was obtained from a low energy area (depression) in which fines and other light debris would settle and therefore is not representative of channel material.

The pollutant levels of the final set of samples were also significantly different from the average levels of the previous three sets. As previously mentioned, these three were collected from the

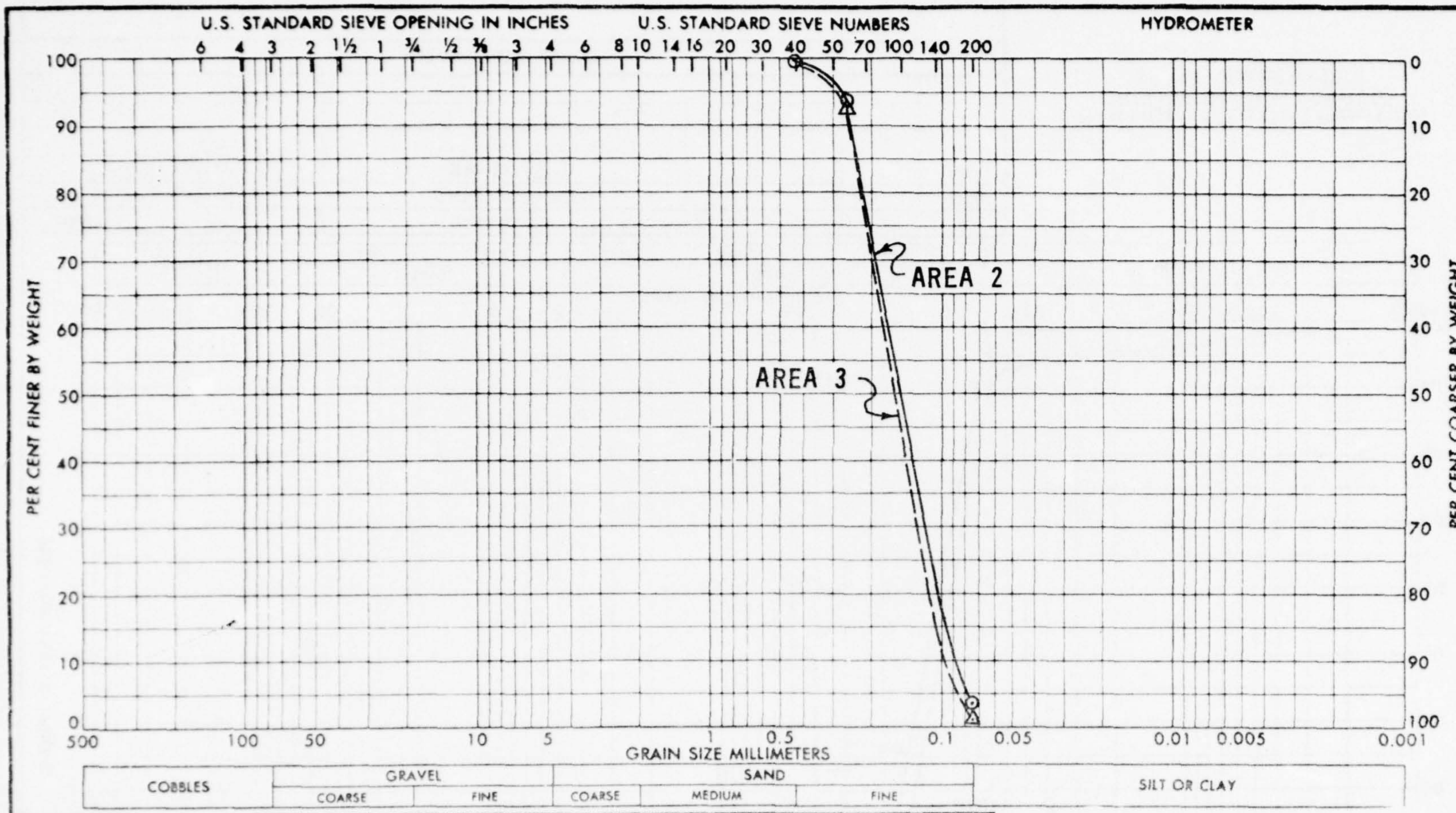


SAMPLE NO		CLASSIFICATION	NAT W%	LL	PL	PI
NEAR	BOUY 3	SAND (SP–SM)				NP
NEAR	BOUY 7	SAND (SP)				NP

GRADATION CURVES

PARTICLE SIZE DISTRIBUTION
DREDGE INTAKE SAMPLES
28 DECEMBER 1970

FIGURE 5



SAMPLE NO	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI

GRADATION CURVES

PARTICLE SIZE DISTRIBUTION
DISPOSAL AREA SAMPLES
27 MAY 1971

FIGURE 6

TABLE 1

COMPARISON OF CHEMICAL ANALYSIS DATA
MAIN SHIP CHANNEL

Parameter (% dry weight)	EPA Limit	28 Dec 70 Samples	5 Apr 71 Samples			8 Jun 71 Samples	18 Jan 72 Samples		
			Station 1	Station 2	Station 3		West End	East End I	East End
Chemical Oxygen Demand	5.0	0.174	0.680	2.60	0.50	0.165	0.33	0.17	0.36
Oil - Grease	1.5	0.035	0.1	0.1	0.1	0.04	0.04	0.03	0.01
Total Kjeldahl Nitrogen	1.0	0.13	0.022	0.062	0.012	0.017	0.01	0.01	0.01
Volatile Solids	6.0	--	2.1	3.9	1.4	1.19	1.3	1.0	1.3
Trace Materials (% dry weight x 10^{-4})									
Lead	50.0	4.79	14.20	27.20	12.20	13.00	6.3	1.2	8.8
Mercury	1.0	0.08	0.02	0.03	0.01	0.03	0.005	0.002	0.01
Zinc	50.0	37.81	48.6	79.90	34.50	55.0	27.0	18.0	31.0
Arsenic		0.01							
Chromium		1.99							
Cadmium		2.08							
Copper		1.67							
Nickel		37.90							
Total Phosphates		32.90							
Total Sulfides		0.28							
Pesticides (parts per billion)									
OP' DDE			0.54	1.64	0.42				
PP' DDE			1.34	1.64	0.58				
PP' DDD			1.34	1.23	--				
OP' DDT			0.54	--	--				
PP' DDT			3.74	2.47	0.95				
Arochlor 1254			--	19.60	Trace				

TABLE 2

STATIC BIOASSAY USING 3-SPINED STICKELBACK FISH
5 APRIL 1971 SAMPLES, MAIN SHIP CHANNEL

96-HOUR TEST	Temp. °C	Control 1 Dilution Water	Composited Sample with Steinhardt Seawater Dilution					Control 2 Holding Water
			1.0 kg	0.56 kg	0.32 kg	0.18 kg	0.10 kg	
START	16.0							
No. of Fish		10	10	10	10	10	10	10
EC in micro-mhos/cc		35,000	35,000	35,000	35,000	35,000	35,000	8,300
DO in ppm		8.2	7.8	7.8	8.0	7.9	8.1	8.2
Turbidity in JTU		2	100	80	75	55	28	3
24 HOURS	17.0							
No. of Fish Survived		10	10	10	10	10	10	10
EC in micro-mhos/cc		35,000	35,000	35,000	35,000	35,000	35,000	35,000
DO in ppm		7.8	7.6	7.6	7.8	7.7	7.6	8.0
Turbidity in JTU		2	15	10	10	8	5	3
B								
48 HOURS	17.0							
No. of Fish Survived		10	9	10	10	10	9	10
EC in micro-mhos/cc		35,000	35,000	35,000	35,000	35,000	35,000	35,000
DO in ppm		8.0	7.6	7.7	7.7	7.8	7.8	8.1
Turbidity in JTU		2	5	5	5	4	3	3
72 HOURS	18.2							
No. of Fish Survived		10	9	9	10	10	7	10
EC in micro-mhos/cc		35,000	35,000	35,000	35,000	35,000	35,000	8,300
DO in ppm		8.1	7.7	7.9	7.8	7.6	7.8	8.1
Turbidity in JTU		2	5	4	5	4	3	3
96 HOURS	17.0							
No. of Fish Survived		10	9	9	10	10	7	10
EC in micro-mhos/cc		35,000	35,000	35,000	35,000	35,000	35,000	8,350
DO in ppm		8.0	8.1	8.1	7.9	8.0	7.9	8.3
Turbidity in JTU		2	5	5	5	4	3	3

Note: EC = Electrical Conductivity, DO = Dissolved Oxygen, JTU = Jackson Turbidity Unit

dredge's hoppers, not its intake pipe. Their lower pollutant levels probably result from first a reduction in the percentage of fines in the hopper caused by hydraulic separation during the loading operation with subsequent discharge in the overboard and secondly, the lower fine content of the material in the deeper levels of the channel exposed by the "new work" dredging. The majority of pollutants seemed to be contained in the fine sediment fraction (Refs. 13 and 14). The elutriation in the hoppers and the reduced silt-clay fraction in the "new work" material support this hypothesis.

A comparison of the sediment analysis data with the 1971 Dredged Spoil "Criteria" show that all measurements, with the exception of the zinc levels obtained on 5 April and 8 June 1971, are within the stated limits and therefore considered not polluted. The material is fine sand (95 percent) and by the new Ocean Dumping Criteria (Marine Protection, Research and Sanctuaries Act of 1972, Public Law 92-532) is considered not polluted (Paragraph 227.61). The sediments dredged from the channel are approximately the same size as sediments in the disposal area. The low levels of pollutants and the compatibility of the sediments implies that the sediments are not deleterious to marine organisms because of either pollutants or substrate alteration.

WATER QUALITY

Program

The water quality monitoring program was initiated to determine the effects of the dredging and disposal operations on the water column. This program included measurement of temperature, salinity, conductivity, pH, dissolved oxygen and turbidity before, during and after operations in 1971 and 1972. Background readings of these parameters were obtained in the Main Ship Channel on 5 April 1971, and in the disposal sites on 8 June 1971 and 9 February 1972. On 10 and 18 June 1971, and on 8 and 10 February 1972 monitoring was conducted to measure parameter fluctuations during material releases in the disposal areas. (Note: The 1971 disposal area was 3,000 feet south of the channel and the 1972 area was 6,000 feet south.) On 10 February during sediment disposal three transects were run in and adjacent to the dredge's overflow plume. At this time water samples were taken at the end and midpoint of each transect for analysis of BOD and COD levels. The post-dredging monitoring was conducted on 30 June 1971.

In 1971, water quality monitoring was handled under a Corps of Engineers' contract with Towill, Incorporated. Towill utilized a Wallace-Tiernan bathythermograph for temperature/depth profiles. Salinity was determined by a Bissett-Merman Model 6210 Induction Salinometer, and the water samples were obtained with a Frautschy Bottle. Surface water temperatures were measured with a standard

laboratory thermometer. Densities were computed using Knudsen's tables (Ref. 15) and dissolved oxygen was determined using the Winkler Titration method (Ref. 12).

During the second year's studies, measurements were taken by District personnel using in-house and Environmental Protection Agency equipment. The instruments used included a Beckman Instruments RB3 Solu Bridge, and Beckman Model N pH Meter. Water samples for these two instruments were obtained with a 3-liter Van Doran Bottle. In situ measurements of dissolved oxygen, temperature and turbidity were made with a Weston-Stack Model 300-C Temperature Dissolved Oxygen Meter and a Hydro Products Transmissometer (1 meter light path, towed). The instruments were calibrated daily prior to the monitoring operation.

The San Francisco Regional Water Quality Control Board order of 27 May 1971, outlined water quality requirements for the San Francisco Bar. These requirements are:

a. The discharge shall not create a nuisance as defined in Section 13050 (m) of the California Water Code.

b. The waste discharge shall not cause:

(1) Visible, floating, suspended, or deposited oil or other products of petroleum origin in waters of the State at any place.

(2) Water of the State to exceed the following limits of quality at any point:

pH	7.0, minimum 8.5, maximum
Dissolved Oxygen	5.0 mg./l. minimum
Other substances	Any one or more substances that impair any of the protected beneficial water uses or make aquatic life or wildlife unfit or unpalatable for human consumption.

(3) Waters of the State at any point more than five hundred (500) feet from points of discharge:

Floating or suspended macroscopic particulate matter or foam.

Alteration of apparent color beyond present background levels.

Increased turbidity above background levels by more than the following:

Receiving Water Background	Incremental Increase
50 units	5 units maximum
50-100 units	10 units maximum
100 units	10 percent of background maximum

Test Results

During 1971, background measurements for temperature, salinity and turbidity were obtained on 5 April, 8 and 30 June, however, these parameters were not monitored during the release periods on 10 and 18 June. Hence, analysis of the effect of the operation on these three parameters were not performed nor was comparison with the Regional Water Quality Control Board requirements possible. The results of these measurements are shown in Table 3. The dissolved oxygen and pH values of the samples collected were within the stated requirements although there were significant fluctuations of the dissolved oxygen level. The fluctuations occurred preceeding (6.3 ppm) and following (6.5 ppm) the second release with a reduction in oxygen concentration greater than two parts per million. However, the levels recorded thirty minutes after the first release (8.7 ppm) and ten minutes after the third release (8.8 ppm) were similar to background levels for the Bar area. Without additional data it is difficult to conjecture what happened during the period of the second release. Measurements of turbidity in the water colunm were not made during 1971, however, aerial photographs were taken to help delineate the area influenced.

TABLE 3

WATER QUALITY
Main Ship Channel and Test Site
1971

Location, Date and Time			Release Time	Depth (m)	Temp. (°C)	Salinity (o/oo)	Density	D.O. (ppm)	pH	Turbidity (JTU)
Main Ship Channel	5 Apr	(pre-) (dredge)		6	11.2			7.1	7.3	<5
Disposal Area #1	8 Jun	0600		0	10.2	33.49	25.76			
		0600		5	9.7	33.51	25.81			
		0600		10	9.5	33.80	26.12			
		1300		0	10.5	33.49	25.71			
		1300		5	10.1	33.56	25.85			
		1300		10	9.7	33.77	26.18			
		1700		0	10.6	33.58	25.77			
		1700		5	10.6	33.46	25.66			
		1700		10	10.2	33.64	25.88			
		2300		0	9.9	33.63	25.93			
		2300		5	9.4	33.81	26.15			
		2300		10	9.4	33.84	26.16			
	10 Jun	1240	1227	3				7.2		
	18 Jun	0801	0736	3				8.7	7.7	
		1015		3				6.3	7.7	
		1129	1047	3				6.5		
		1240	1230	15				8.8	7.7	
Main Ship Channel	30 Jun	(Post-) (dredge)		6	10.5			7.1	<5	

On 8 February 1972, parameter measurements were taken preceeding, during and following two material releases in the new disposal area 6,000 feet south of the Main Ship Channel. The following day, 9 February, while the dredge docked for fuel and supplies, measurements at background level were obtained. On 10 February, the dredge returned to work and three one-mile transects were run in the disposal area. One of the transects (Aw to Ae) was run through the long axis of the dredge's release and the other two (Bn to Bs and Cn to Cs) perpendicular. The positions of these transects are shown on Figure 7. The measurements for 8, 9 and 10 February are shown in Table 4. The following is a discussion of test results for 8 thru 10 February 1972:

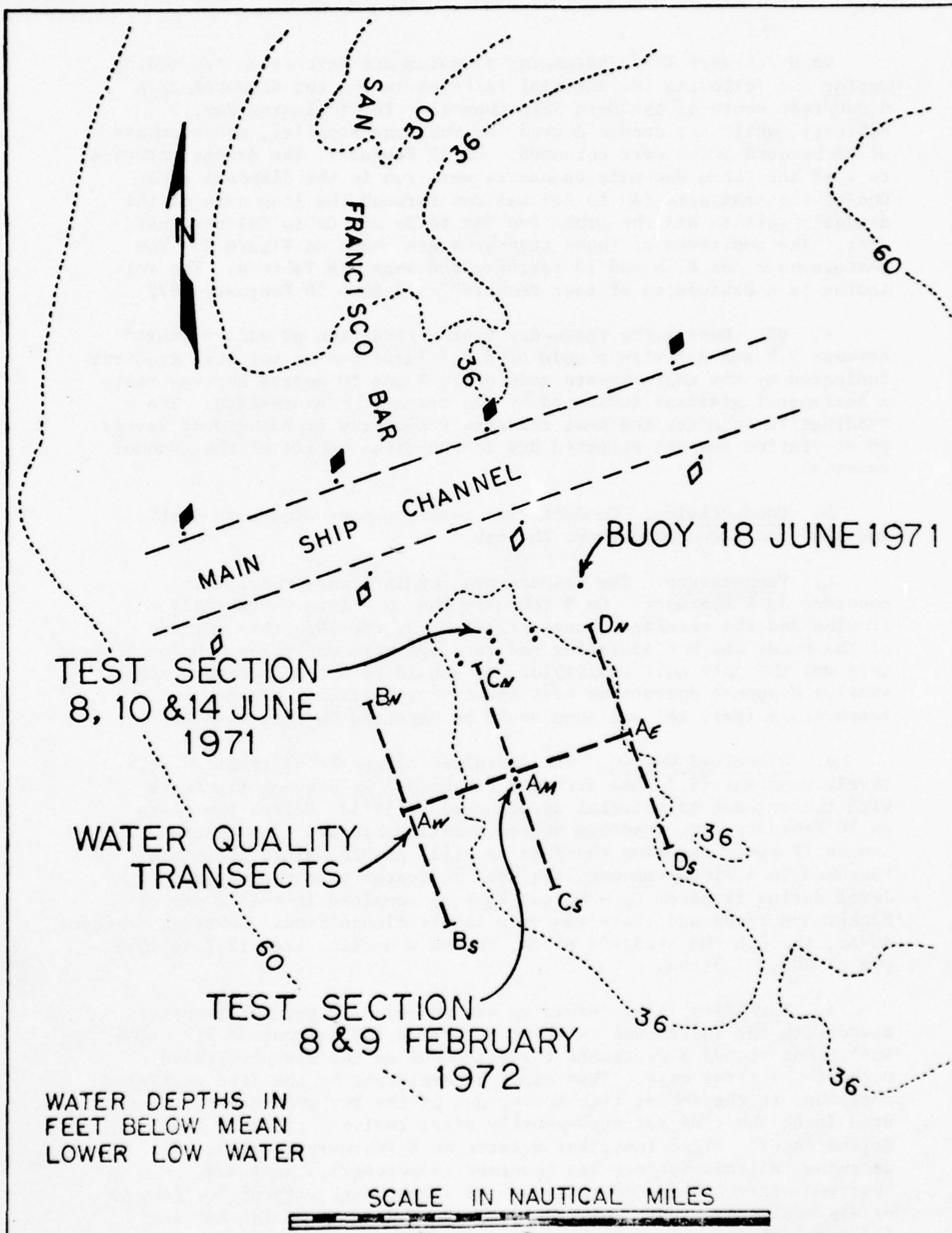
a. pH. During the three-day test period, the pH values ranged between 7.9 and 8.1 with a mode of 8.0. There was no vertical gradient indicated by the measurements made at 1, 5 and 10 meters nor was there a horizontal gradient indicated by the transect measurements. The readings taken after the test releases registered at background levels. pH aberration was not expected due to the clean nature of the channel material.

b. Conductivity. Conductivity readings increased with depth and also increased throughout the day.

c. Temperature. The temperature readings were relatively constant on 8 February. On 9 February the thermistor began malfunctioning and the readings became erratic. By the 10th this portion of the meter was not operating and readings were not taken. Unfortunately this was the only unit available. It should be noted, however, other similar disposal operations have shown no significant effect on temperature (Ref. 16) and none would be expected in this case.

d. Dissolved Oxygen. The dissolved oxygen level remained relatively constant (9.2 ppm) during 8 February. It did not fluctuate with the release of material as occurred in 1971. During the tests on 10 February, the readings became questionable drifting upwards to around 12 ppm. Assuming the data is still usable, since the probe responds in a linear manner, the data indicates that the oxygen level during transect $C_N - C_S$ and $B_S - B_N$ remained in the 12 ppm of background range and there was very little fluctuation. However, transect Aw-Ae, through the dredge's plume, showed a decline from 12.2 to 10.8 ppm or about 1.5 ppm.

e. Turbidity. The turbidity was measured in percent transmittance with the instrument calibrated to read 100 percent in air. The instrument showed a decreased transmittance as the day progressed each of the three days. This might be explained by the fine particles suspended in the ebbing tide moving out of the Bay and into the test area (peak ebb tide occurred shortly after twelve o'clock at the Golden Gate). After the first release on 8 February a slight decrease in transmittance was observed (9 percent). None was observed after the second release. On 9 February, without dredging or disposal operations, the values were much higher in the morning (43 percent) than the previous morning (32 percent) but by late



TEST LOCATIONS

TABLE 4

WATER QUALITY
TEST SITE
1972

Location, Date and Time			Release Time	Depth (m)	Temp. (°C)	Conduct. (K=20)	D.O. (ppm)	pH	Turbidity (% Trans.)
Disposal Area #2	8 Feb	1020		1	10.1		9.2	7.9	32
		1050		5	10.2		9.05	7.9	24
		1120	1108	1	10.0		9.1	8.0	23
		1150		5	10.0		9.2	7.7	22.5
		1220		1	10.0		9.2	7.9	22.5
		1250		5	10.2		9.2	8.0	23.5
		1320		1	10.0		9.25	8.0	24
		1350		5	10.05		9.3	7.9	23
		1420	1427	1	10.0		9.25	8.0	23
		1450		5	10.0		9.35	8.0	23.5
		1520		1	10.05		9.3	8.0	24
	9 Feb	0900		1	10.5	3000	9.3	7.9	43
		0920		5		3500		7.9	
		0930		10	11	3950	9.0	7.9	42
		0940		1		3300		7.9	
		0950		5		3500		8.0	
		1000		5	12		9.2		46
		1010		1		3900		7.9	
		1015		5	12		9.2		44
		1020		5		4000		7.9	
		1030		1		4500		8.0	
				5	12.5		9.6		40
		1040		1		4000		8.0	
		1045		5	12		9.6		38
		1050		5		4200		7.8	
		1100		5	12		9.1		40
				10		4400		7.9	

TABLE 4 (Cont'd)

Location, Date and Time	Release Time	Depth (m)	Temp. (°C)	Conduct. (K=20)	D.O. (ppm)	pH	Turbidity (% Trans.)
Disposal Area #2 9 Feb 1110		1		3100		7.9	
1115		5	12		8.9		38
1120		5		4150		7.9	
1130		5	14		9.4		33
		10		4500		8.0	
1140		1		4050		7.9	
1145		5	15.5		9.4		24
1150		5		4300		7.9	
1200		5	12		9.3		21
		10		4500		8.0	
1300		1		4100		7.9	
		5	12		9.9		24
1310		5		4400		8.0	
1315		5	12.5		9.9		25
1320		10		4400		8.0	
1330		1		4100		7.9	
		5	12.5		9.7		23
1340		5		4400		7.9	
1345		5	13		9.5		24
1350		10		4550		7.9	
1400		1		4100		7.8	
		5	12.5		9.6		25
1410		5		4400		7.8	
1415		5	14		9.5		25
1420		10		4500		7.8	
1430		1		4000		7.9	
		5	16		9.4		26
1440		5		4500		7.9	
1445		5	15		9.8		30
1450		10		4550		7.9	

TABLE 4 (Cont'd)

Location, Date and Time	Release Time	Depth (m)	Temp. (°C)	Conduct. (K=20)	D.O. (ppm)	pH	Turbidity (% Trans.)
Disposal Area #2 9 Feb	1500	1		4000		7.9	
		5	14		9.7		25
	1510	5		4500		7.9	
	1515	5	12.5		9.8		26
	1520	10		4700		7.8	
	1530	1		4000		8.0	
		5	13		9.8		25
	1540	5		4100		7.9	
	1545	5	16		9.6		18
	1550	10		4900		7.9	
	1600	1		4000		7.9	
		5	17		9.8		18
	1615	5		5100		7.9	
		5	13.5		9.6		16
	1630	5	16.5		9.0		18
		10		5800		7.8	

TABLE 4 (Cont'd)

Location, Date and Time		Transect Position	Depth (m)	H_2O Sample BOD	COD	Conduct. (K=20)	D.O. (ppm)	pH	Turbidity (% Trans.)
Disposal Area #2 10 Feb	1035	Cn	1 & 3*	0	24	3200	11.5	8.1	46
	1037		3				12.0		50
	1039		3				12.8		48
	1041		3				12.8		44
	1042	Am	1	0	31	3700		8.1	
	1043		3				12.8		48
	1045		3				12.3		44
	1047		3				12.1		44
	1049		3				12.4		43
	1051	Cs	1 & 3*	0	26	3600	12.1	8.0	40
	1107	Bs	1 & 3*	0	24	3500	12.0	8.1	42
	1109		3				12.5		45
	1111		3				12.6		56
	1113		3				8.0		57
	1115		3				12.0		54
	1117		3				12.0		51
	1119	Aw	1 & 3*	0	29	3800	12.2	8.1	52
	1121		3				12.2		56
	1123		3				11.8		48
	1125		3				12.1		52
	1127		3				11.9		54
	1129		3				12.0		64
	1131		3				12.0		65

*Water Samples pH and Conductivity Taken at 1 meter Turbidity and Dissolved Oxygen taken at 3 meters.

TABLE 4 (Cont'd)

Location, Date and Time			Transect Position	Depth (m)	H_2O Sample BOD	H_2O Sample COD	Conduct. (K=20)	D.O. (ppm)	pH	Turbidity (% Trans.)
Disposal Area #2	10 Feb	1131.5	Bn	1	0	24	3700		8.1	
		1146	Aw	3				12.2		35
		1148		3				12.0		28
		1150		3				11.8		22
		1152		3				11.7		34
		1154		3				11.6		34
		1155		3				11.5		36
		1156	Am	1 & 3*	0	31	3500	10.8		30
		1202		3				11.4		20
		1203		3				11.2		15
		1205		3				11.0		12
		1207		3				11.1		8
		1209		3				10.8		8
		1210	Ae	1 & 3*	0	31	3800	10.8	8.0	8

*Water Samples pH and Conductivity taken at 1 meter Turbidity and Dissolved Oxygen taken at 3 meters.

afternoon were lower than those previously encountered. The turbidity measurements on 10 February indicate that the water north of the disposal area was clearer than the water to the south. This could be caused by the ebbing waters from the Golden Gate carrying the fines away from the disposal operation towards the southwest. Current plots discussed in the Material Dispersing Section show the mass movement of surface water is in this direction as the tidal state changes from higher high water to lower low water. Transect Aw-Ae shows a definite influence from the dredge's plume. The value decreases from 35 percent to around 10 percent, a change of 70 percent from the background level. Unfortunately, the observations were not continued to determine how quickly these levels return to background or if these were new background levels associated with the ebbing tide.

Discussion

Neither the dredging nor disposal operation seem to have any measurable or expected effect on the conductivity or the temperature of the water mass. Any observed change in these parameters are probably the results of Mother Nature's work or more frequently the result of probe aberration. This includes use of the inappropriate equipment, probe malfunction, etc. By comparison the effects of dredging and disposal operations are negligible.

Hydrogen ion concentration (pH) is another parameter which predictively does not give a measurable response as a result of dredging or disposal operations. The sample obtained on 28 December 1970 from the area of Buoy 7 had a pH of 7.6. The sediments in the Bay have been reported to range between pH 7 and 7.5 (Ref. 17). This neutral sediment will have no appreciable effect on the hydrogen ion concentration of the water mass which in itself is buffered. Water column readings were always between pH 7.7 and 8.1 which is well within the pH range found in seawater (Ref. 5).

The dissolved oxygen reductions may be a function of one or a combination of factors. First, the resuspended material can exert a biochemical oxygen demand which will consume oxygen at varying rates and to varying degrees depending on conditions. Second, readings can be a function of electronic problems, i.e., (1) dilution of the water mass by the suspended particulates giving an erroneous picture of the actual oxygen concentration of the water, or (2) denaturing of the probe's membrane during operations resulting in a slow deterioration in the accuracy of the readings. Any of these factors will result in data which indicates a reduction in dissolved oxygen.

It is unlikely the material had an appreciable oxygen demand. The chemical oxygen demand (COD) of the sediments excluding the results of the 5 April 1971 sample at Station 2 average 31 mg/l. This is approximately the same level as found in the water column during

the sampling operation on 10 February 1972. The samples taken outside of the area influenced by the plume had an average demand (COD) of 24.5 mg/l. The samples taken in the area of influence averaged 30.5 mg/l. In neither case did the water show a biochemical oxygen demand. Chemical oxygen demand analysis is performed by oxidizing organic and oxidizable inorganic substances with a potassium dichromate solution in 50 percent sulfuric acid solution. This harsh oxidation reaction does not occur in the real world. There is always a certain amount of oxidizable matter in solution as indicated by the background samples (outside of the area of influence). Therefore, it is unlikely that the oxygen fluctuations recorded in 1971 and 1972 occurred as a result of oxygen consumption by the resuspended sediments.

The lower levels recorded prior to and following the third release in 1971 were probably the result of variations in the natural system or the technician performing the titrations. The duration of time between the releases and the water samples, in all cases, was well beyond the time required for any oxygen demand of this sediment to be satisfied. The fluctuations recorded during the 1972 transects are probably the result of probe malfunction. Further experiments using this probe have indicated that when it is suspended in a turbid solution, fine particulates infiltrate the case and cause aberrant readings.

During dredging operations two plumes have been identified (San Francisco District, unpublished data): (1) a surface plume resulting from overboarding, and (2) a bottom plume resulting from perturbation by the dragheads and the dredge's screws. The surface plume is generated by the overflow of fines separated during the loading of the hoppers.

Two plumes, one at the surface and one in the lower water column, are generated during disposal operations. The surface plume is the result of surcharging prior to opening the gates. The surcharge is necessary to breakup the material and prevent arching in the bin. The plume in the lower water is generated from the actual release of the material (the hopper gates are approximately 15 to 20 feet below the surface), its movement down to bottom and any subsequent resuspension due to impact with the bottom. The bottom plume associated with the dredging operation in the channel is probably inconsequential because of the depth of water and the mean particle size of the sediments being moved. The bottom plume resulting from the disposal operation is discussed in a qualitative manner in the Material Dispersal section.

To obtain a qualitative estimate of the surface plume, aerial photographs were taken of operations on 14 June 1971 using Kodak Aerocolor Negative Film 2445 and GAF 1000 Blue Insensitive Color Film Type 2575 at scales of 1:6,000 and 1:9,000 during slack and flood currents.

The photographs using the non-blue emulsion film were overexposed and interpretation of the imagery was not possible. Color photographs showed discoloration greatest during the dredging in the channel. This corresponds with the observations made from the dredge and at test site during operations.

The discoloration is a result of fine material being introduced into the water column from the overflow of the hoppers. The photographs showed that dispersion of fine material in suspension occurs rapidly. The concentration of the suspended material is diluted and the discoloration vanishes within a few minutes after the dredge passes. Photographs of the dredge in transit and other vessels in the area indicated slow settling rates for the fine material. In both cases, the wash from the vessels propellers re-agitated the fine material and again discolored the surface water.

Low altitude aerial photography on 8 February 1972 used Kodak EF 8442 color positive film with a yellow filter. The combination of film, filter and exposure has been found to provide the greatest resolution of suspended sediments. However, the photographs showed no discoloration at the test site following the release of material. The lack of discoloration is probably due to the decrease of fines and increase in median grain size of the material being dredged with the new construction.

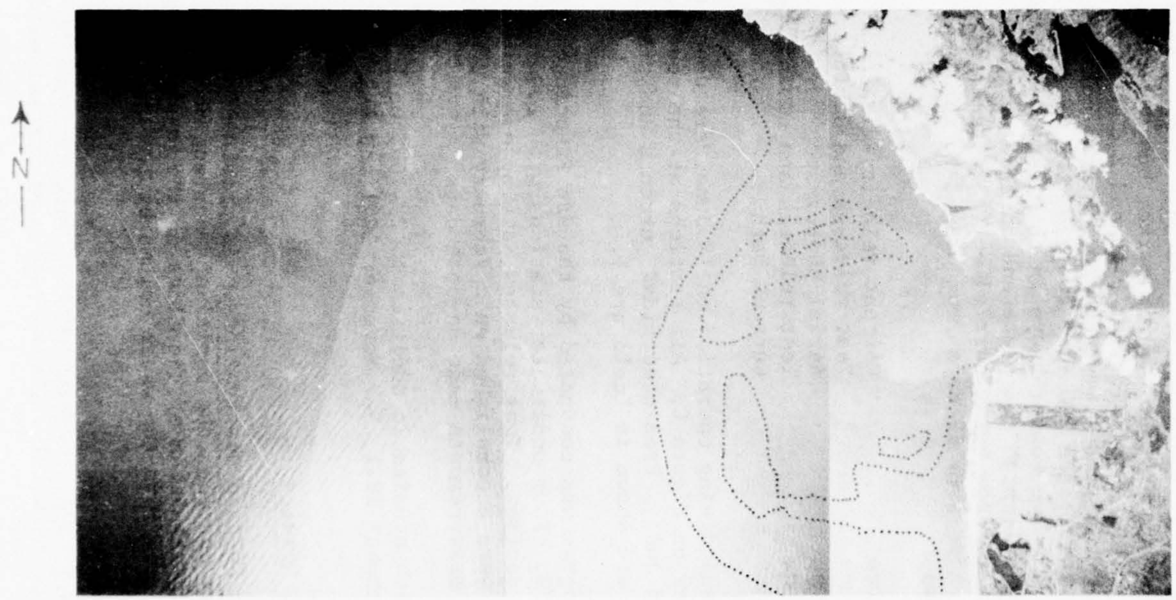
High altitude remote sensing, including earth satellite simulation photography experiments, were utilized to interpret the larger scale suspended sediment patterns off the Golden Gate and along the California coast. Photograph 2 shows the extent of the natural plume from the Golden Gate as it relates to the coastal currents about 10 miles off the Golden Gate. Several tidal plumes can be distinguished in the photograph.

Based on information gained from the aerial photographs the turbidity readings obtained with the transmissometer during 1972 were probably reflecting the suspended particulate concentration in the water ebbing from the Bay rather than discoloration from the disposal operation.

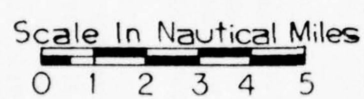
MATERIAL DISPERSION

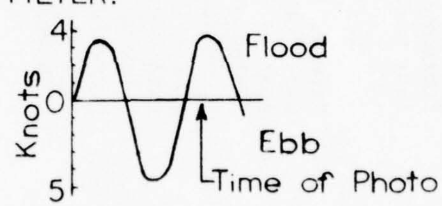
Program

Three programs were developed to determine the material dispersion and deposition. They were (1) aerial and surface observations, (2) bottom deposition evaluation using measurements and sampling at specified underwater stations, underwater photography and observations, and (3) current measurements including both current velocity-direction



PHOTOGRAPH 2 - THREE FRAMES FROM NASA EARTH RESOURCES AIRCRAFT PROJECT, MISSION 123, SITE 211, 10 MARCH 1970, 50,000 FEET, FALSE COLOR INFRARED, YELLOW FILTER.





and current path. The programs were conducted during June 1971 and February 1972 except for the current paths which were conducted on four occasions.

The initial program in June 1971 was conducted by the consulting firm of Towill, Inc. A test site was established by the San Francisco District about 3,000 feet south of the Main Ship Channel in 35 to 40 feet of water as shown on Figure 7. Six marker buoys were placed to define a dredge release course 200 feet wide and 2,000 feet long with 1,000 feet marker spacing and a test section perpendicular to the dredge course with two markers, each 200 feet out from the dredge course. Actual width between the two center buoys in the test section was 400 feet. Delay in dredge arrival, high sea state and adverse weather conditions prevented the programs from being carried out simultaneously. The actual study was extended over 19 days from 8 June to 26 June. The studies were as follows:

8 June	Current velocity-direction
10 June	Test releases and diving operation
14 June	Aerial photography
18 June	Test releases and diving operation
25-26 June	Current Path

The test releases and diving operation on 18 June were done at one station as indicated on Figure 8. All stations at the test section had been lost by 18 June. Predicted tidal currents and test releases and sea state data are shown in Inclosure 1.

The second program was conducted by the San Francisco District on 8-9 February 1972. Four underwater stations with 200-foot spacing established a test section. Test releases, diving operations and aerial photography were accomplished on 8 February with current velocity-direction measurements made on both days.

The current path studies in addition to 25-26 June 1971 were conducted on 1-2 October 1971, 5-7 November 1971 and 1-2 February 1972.

Test Operations and Results

a. Aerial and Surface Observations. As previously discussed in the water quality section, the aerial and surface observations were limited to the evaluation of the fines in the dredged material as they were introduced into the water column by the overflow of the hoppers.

b. Bottom Deposition. Several methods were employed to measure deposition of dredged material. Divers were used for all methods.

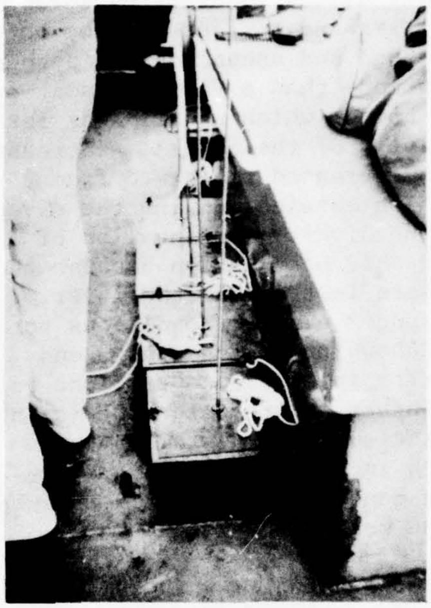
During the diving on 10 June, only three stations were utilized due to sea state conditions. The divers encountered strong currents on the surface and strong surges and currents at the bottom. This required the divers to descend and ascend on the anchor lines and prohibited them from moving more than a few feet away from the anchor. The visibility near the bottom which usually was less than three feet also limited the activity of the divers. Increasing fatigue among the divers coupled with increased sea state from 2 to 6 feet reduced the resultant information obtained during the dives and necessitated cancelling some of the dives. Continuation of diving operations on 18 June employed only one station because the buoys marking the original stations were lost during the interim. Five dives were made at this station under similar conditions to those on 10 June. Plates and stakes shown on Photographs 3 and 4 were placed and observed on the bottom for diving operations on 10 and 18 June. The plates were 12 inches square with a surfacing to correspond with the roughness of the sand. The stakes, three inches in width, were marked in 3-inch increments. All three releases on 10 June were made along the centerline of the established course. The three releases on 18 June were made as follows:

1st release	60 feet south of station
2nd release	60 feet south of station
3rd release	400 feet south of station

Underwater photography of the stakes was not successful due to the light reflection from the sediment in suspension.

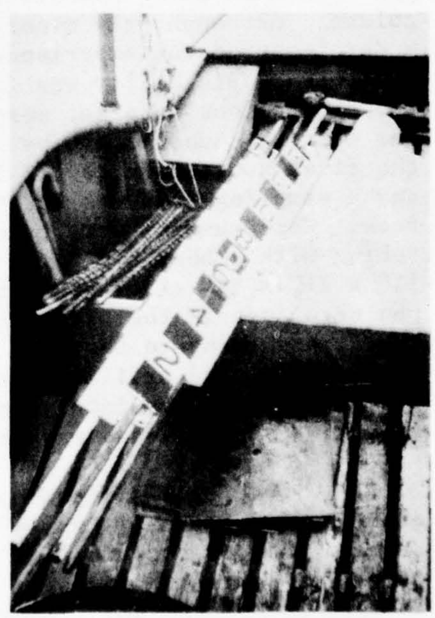
Four stations were placed and monitored before and after two test releases on 8 February. Strong currents up to 2.3 knots were encountered by the divers in the upper 15 feet of the water column. Although only minor currents were detectable below 15 feet, moderate surge was experienced in the lower water column. Up to two feet of visibility was found on the bottom. At each station, two substations were set perpendicular to and about 15 feet from the station anchor chain by means of tielines and driven rebars. At the first substation, a 1/2-inch acrylic rod was placed and marked and a sampling area was established using a plastic-covered dolomite rock. Core samples were taken using one-inch diameter acrylic tubing with rubber stoppers for each end. At the second substation, 13" x 21" x 14" steel pans were provided. However, all but one pan were lost in the strong currents. The substations, rods, pans, tubes, and rock are shown in Photograph 5. Photograph 6 shows the core samples and artificial substrate. The first dredge release on 8 February was immediately north of station 3 (toward station 2) and the second release was made directly over station.

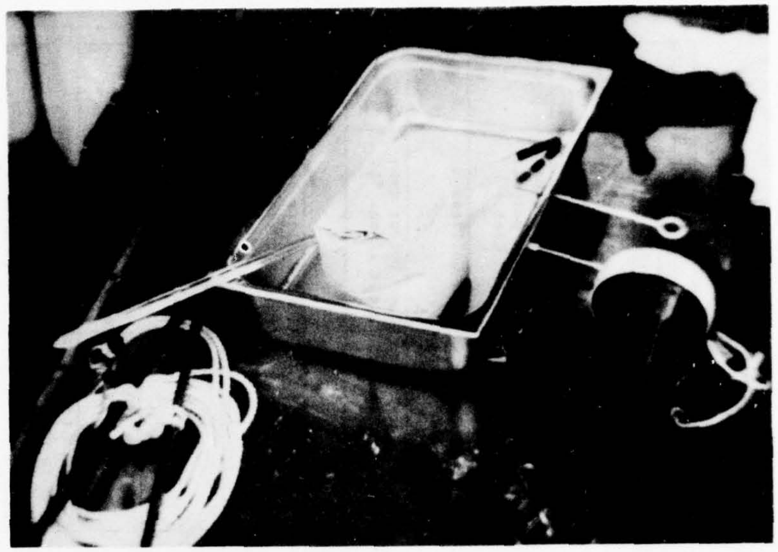
Core sample measurements on 8 February were made using the distinct difference in grain size between the material on top of the Bar and the new construction material from within the Bar. In some cases, the dolomite rock was present between the two strata. Diver fatigue and bottom conditions made location of the rock sampling areas



PHOTOGRAPH 3 - BOTTOM OBSERVATION PLATES, 12"x 12".

PHOTOGRAPH 4 - BOTTOM OBSERVATION STAKES, 3" GRADUATIONS.





PHOTOGRAPH 5 - SUBSTATIONS, ROD, PAN AND BAG OF ARTIFICIAL SUBSTRATE.

PHOTOGRAPH 6 - CORES AND ARTIFICIAL SUBSTRATE SAMPLES.

TABLE 5

DIVING OPERATION DATA
10 JUNE 1971

TEST RELEASE/ DIVE LOCATION	TIME OF DIVE	TIDAL CURRENT/ TIME	PHYSICAL DATA: STAKE READING*	PHYSICAL DATA: ACCUMULATION OR SCOUR	PHYSICAL DATA: VISIBILITY TURBIDITY, CURRENT	PHYSICAL DATA: SEDIMENT CHARACT. TOPO, TYPE, COMPACT	PHYSICAL DATA: TASKS PERFORMED	BIOLOGICAL DATA: MARINE LIFE	BIOLOGICAL DATA: ORGANIC MATERIAL
BEFORE RELEASE									
Buoy 4A	0953	Slack 0936	1.0		Very dark below 15 ft. Suspended sed. in water. Visibility 6 in. Current.	6" unconsolidated sand, compacted below.	Set plate sampler and stake.	Many Sand Dollars, some buried.	None
Buoy 4	1030		2.4		Very dark. Suspended sand in water. Strong current. Divers must hang on to cable.	6" unconsolidated sand. Very loose sand ripples, 4 1/2" x 1 1/2"	Set plate and stake. Attempted core sample. Took grab sample.	Sand Dollars on edge. 12 per sq. ft. 3" Crab.	None
Buoy 3	1128		3.5		Visibility of about 2 ft. Very turbid layer to 10 ft. above bottom.	2" loose sand. Hard underneath.	Set stake only; current too strong to set plate.	Sand Dollars.	None
Buoy 3A	1204		2.0		1 ft. visibility.	Fine sand, 4" ripples, 1" depth	Obtained grab sample. Set stake but not plate.	Sand Dollar density: 12/sq. ft.	None
		Flood 1217							
FIRST TEST RELEASE	1227				*STATION 3A LOST*				
AFTER FIRST AND BEFORE SECOND RELEASE									
Buoy 4A	1310		1.5	Scour is taking place. 6" deep around anchor. No sand on plate.	Visibility 3 ft., current is slacking, no suspended material.			Sand Dollars on edge and flat.	None
Buoy 4	1344		1.9	Some accumulation on plate x 1/2" scouring continuing.	Fine sand in suspension.			Sand Dollars.	None
Buoy 3	1355		1.9		Visibility 2 ft.		Set plate sampler.	Many Sand Dollars on surface and buried.	None
Buoy 3	1436						Attempted to obtain 2" core sample. Drove to 18". Sed. too fluid.		
SECOND TEST RELEASE	1535								
AFTER 2ND RELEASE									
Buoy 4A	1600		1.9	Some accumulation	Same	Same		Same	None
Buoy 4	1609	Slack 1612	2.2	Plate was clear.	Same	Same		Same	None
Buoy 3	1613		could not find	Sed. accumulation on plate sampler 15", could not find to recover	1 ft. visibility, turbid water. Divers could feel suspended sand.	Sed. seemed more compacted.	Attempted core sample. Drove pipe 24". Could not recover.		

*One unit of stake reading equals three inches.

TABLE 6

DIVING OPERATION DATA
18 JUNE 1971

TEST RELEASE 1 STATION ONLY	TIME OF DIVE	TIDAL CURRENT TIME	PHYSICAL DATA: STAKE READING*	PHYSICAL DATA: ACCUMULATION OR SCOUR	PHYSICAL DATA: VISIBILITY TURBIDITY, CURRENT	PHYSICAL DATA: SEDIMENT CHARACT. TOPO, TYPE, COMPACT	PHYSICAL DATA: TASKS PERFORMED	BIOLOGICAL DATA: MARINE LIFE	BIOLOGICAL DATA: ORGANIC MATERIAL
BEFORE FIRST RELEASE	0703	Flood 0717	3.0		Visibility 1-1/2 ft. with light bottom turbid layer extending 15 ft. above bottom. Bottom current slight although there were surges.	Compacted sand. Smooth topography.	Set graduated stake; set sampler plate; photograph of devices in place.	None	None
FIRST TEST RELEASE	0736								
AFTER FIRST RELEASE	0801		2.5	Very little accumulation on plates.	Same.	Same.	Grab sample. Water sample Photographs.	None	None
BEFORE SECOND RELEASE	1015	Slack 1048	2.5 and 3.7	Scour at stake forming 6" diameter depression around stake.	Visibility 1-2 1/2 ft. at 2 ft. above bottom. Bottom layer turbid. No current on bottom.	Divers could dig 14" into sediment with hands	Pipe core sample 18" deep obtained. Water sample. Underwater photographs	None	None
SECOND TEST RELEASE	1047								
AFTER SECOND AND BEFORE THIRD RELEASE	1129		2.5 and 4.2	1/2" sed. accumulated on plate Anchor shows scour. Est. 3-4"	Visibility 1-2 ft. at 3 ft. above bottom and 10 feet above that.	Sand ripples, 3" x 1/2"	Grab sample Water sample Photographs	Sand Dollar density 3-4 ft^2 Small jellyfish 20 ft. above bottom.	None
THIRD TEST RELEASE	1230								
AFTER THIRD RELEASE	1250	Ebb 1241	2.5 and 4.3	No accumulation on plate. Depression around stake 2 ft. in diameter.	Visibility 1 ft. Turbid layer increasing from bottom to surface.	Same	Photographs		None

*One unit of stake reading equals three inches. The second readings are those of the surrounding areas.

difficult on the later dives. The core samples are shown in Photographs 7, 8, 9, 10 and 11. The recovered pan from Station 2 is shown in Photograph 12. Although two of the four rods were recovered, each rod had only one grease mark. The rod from Station 4 also had what appeared to be a knife mark, indicating a scour of 1.5 inches, inconsistent with the cores and pan measurements. Bottom conditions observed were that of compacted sand with hand penetration of from 1/4" to 1/2", sand ripples about 1/4" x 2-1/2", and the presence of shell fragments.

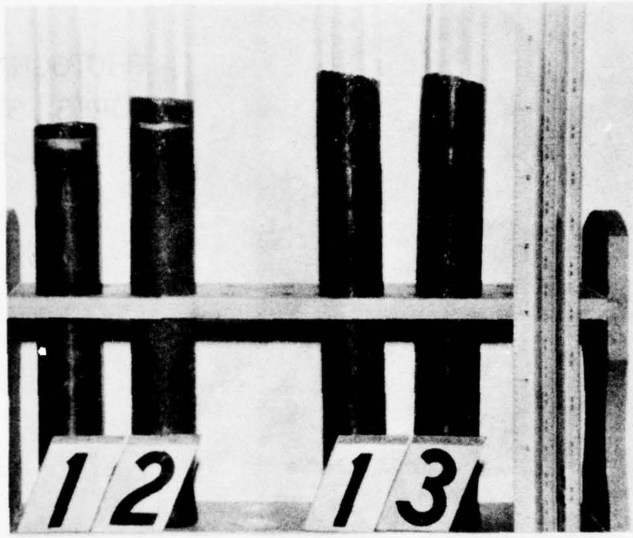
Bottom measurements and observations are tabulated for 10 June and 18 June in Tables 5 and 6, respectively. The accumulation measurements and observations for 8 February 1972 are presented in Tables 7 and 8. The final report entitled "San Francisco Bar Dredge Material Dispersion Study" prepared by Towill, Inc. can be found in Inclosure 2.

TABLE 7

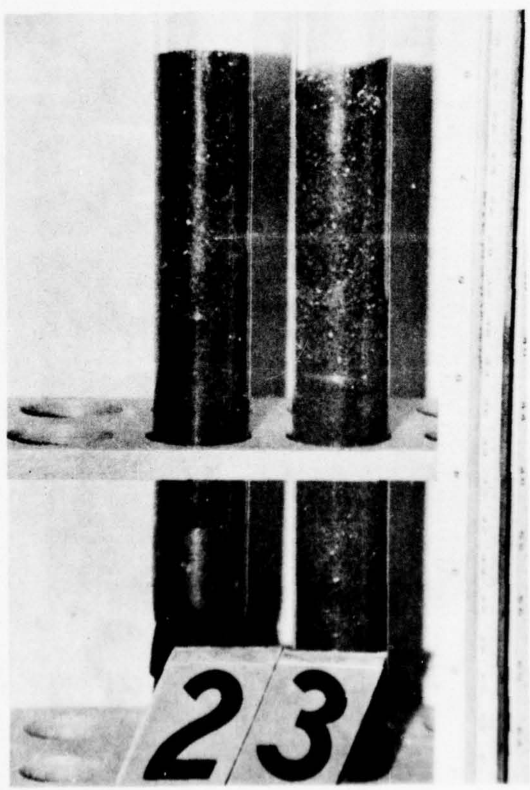
DEPOSITION MEASUREMENTS 8 FEBRUARY 1972

	Station 1	Station 2	Station 3	Station 4
Cores during 2nd dive	0.2 inches 0.5 inches	-	1.8 inches 2.2 inches	-
Cores during 3rd dive	1.1 inches 1.4 inches	2.5 inches 3.2 inches	2.7 inches	0.5 inches
Pan during 3rd dive	-	0.7-1.4 inches	-	-

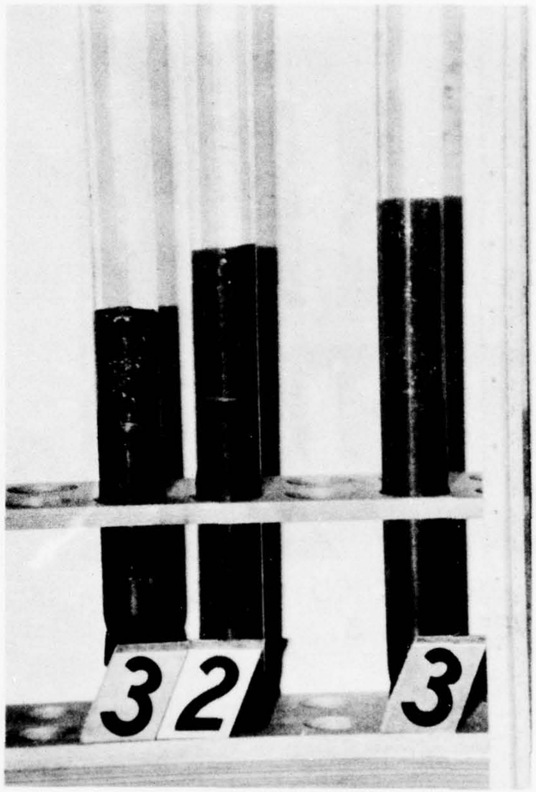
c. Current Measurements. Current velocity-direction measurements were taken over a 24-hour period on 7-8 June 1971 at depths of 1, 6 and 12 meters below the surface. The measurements were made in about -38 feet MLLW at the June test section. The instrument was raised and lowered to obtain a current sampling every hour at each of the three depths. Wind velocity during the test ranged from 10 to 25 miles per hour with sea state varying from 2 to 6 feet. Similar measurements were made on 8 and 9 February 1972 at the February tests section over periods of six and eight hours, respectively. The lower depth used was 10 meters as compared to 12 meters in June. The current velocities for the three days together with the predicted current at the Colden Gate are shown on Figure 8. The directions used to divide ebb and floodflows are 170° to 351° to 171°, respectively, for the 7-8 June plot. All measurements for 8 and 9 February were plotted as ebb flow since the directions are not defined for that area of the Bar and the flows for the Bay are ebbing. However, while measuring in the upper water column when the current was ebbing, measurements at 6 and 10 meters showed a reversal of flow.



PHOTOGRAPH 7 - RECOVERED CORES: STATION 1, DIVES 2 & 3.

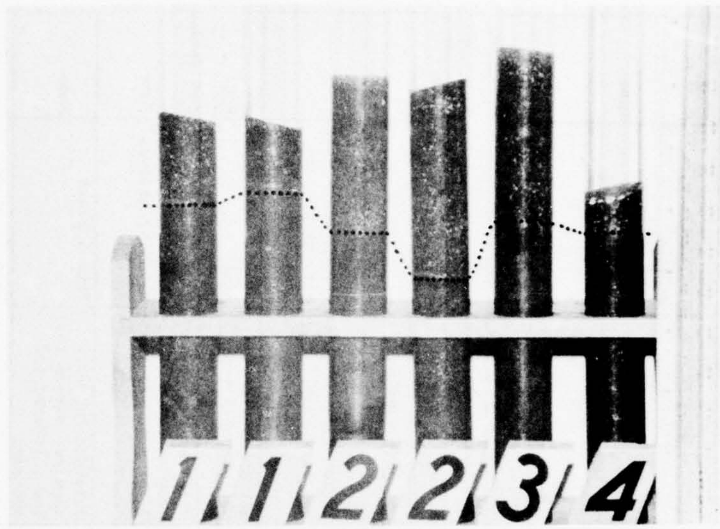


PHOTOGRAPH 8 - RECOVERED CORES: STATION 2, DIVE 3.

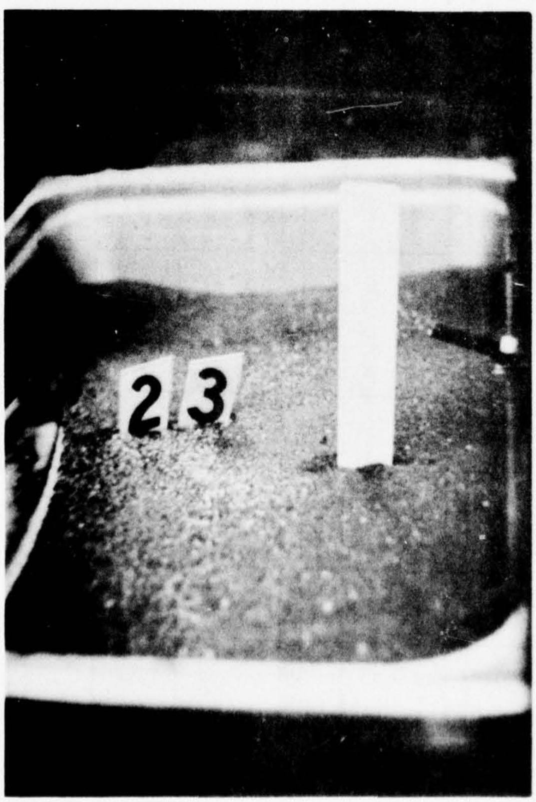


PHOTOGRAPH 9 - RECOVERED CORES: STATION 3, DIVES 2 & 3.

PHOTOGRAPH 10 - RECOVERED CORE: STATION 4, DIVE 3.



PHOTOGRAPH 11 - RECOVERED CORES:
STATIONS 1, 2, 3 & 4, DIVE 3.

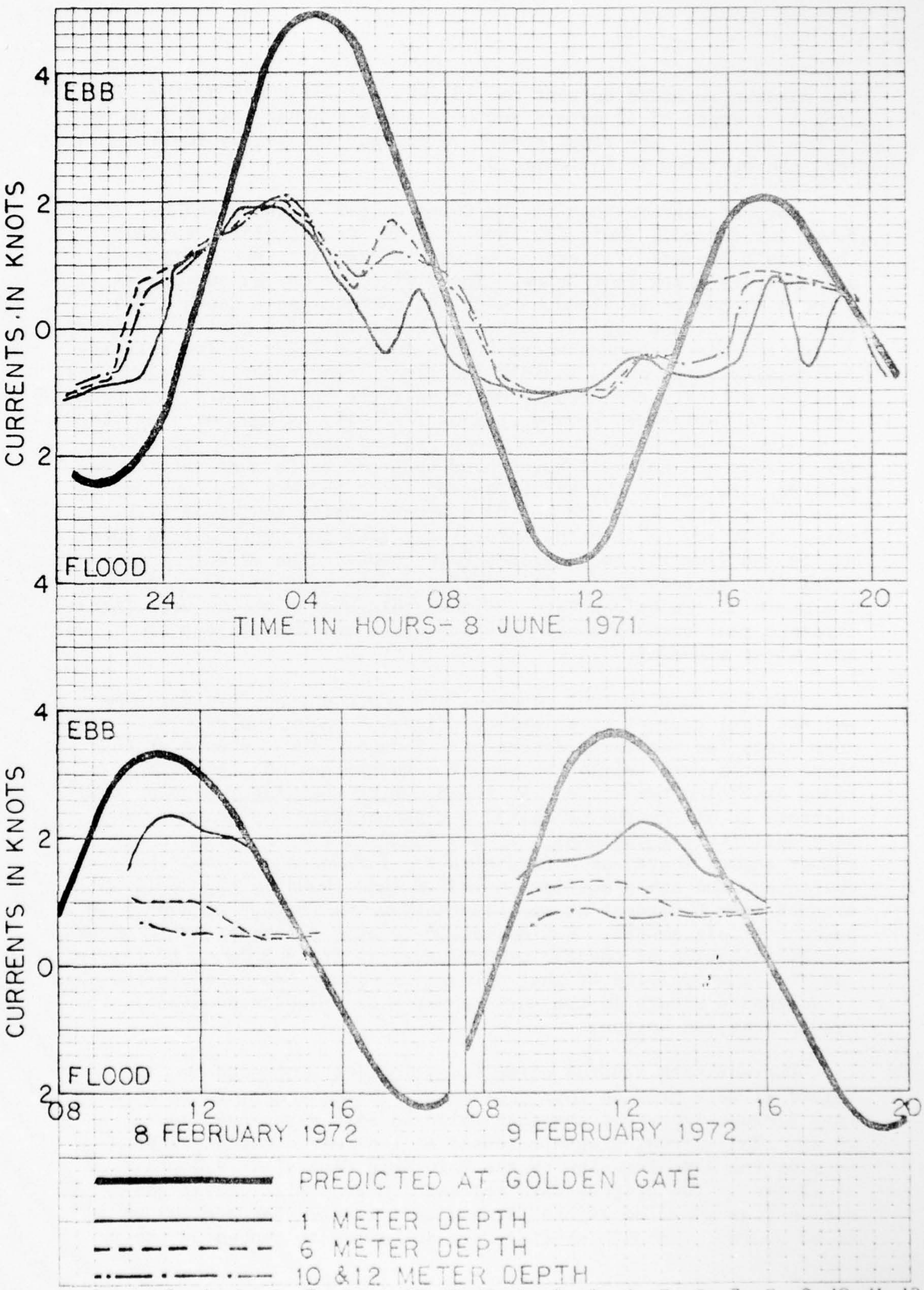


PHOTOGRAPH 12 - RECOVERED PAN: STATION 2, DIVE 3.

TABLE 8

DIVING OPERATION DATA
8 FEBRUARY 1972

TEST RELEASE/ DIVE LOCATION	TIME OF DIVE	TIDAL CURRENT/ TIME	PHYSICAL DATA: CORE NUMBER	ACCUMULATION OR SCOUR	VISIBILITY TURBIDITY, CURRENT	SEDIMENT CHARACT. TOPO, TYPE, COMPACT	TASKS PERFORMED	MARINE LIFE	ORGANIC MATERIAL
BEFORE RELEASE		Slack 0724							
STATION 1	0920				2 feet visibility; no material in suspension observed; moderate bottom surge; no prevailing current.	Fine compacted sand; Can penetrate finger only about 1/4 to 1/2 inch; Ripple marks 7mm ht. and 60mm wave length.	Set substations, yellow rock and rod. Obtained a 3 liter grab sample.	One juvenile Sanddab; dense aggregations of Sand Dollars; 8-14/ft^2	Shell fragments only
STATION 2	0955				2 feet visibility; some material put into suspension by divers. Light surge on bottom, strong surface ebb current.	Fine sand; highly compacted. Penetration only 1/4 inch. Ripple marks, ht. 6-7mm.	Set substations, yellow rock, rod, and pan.	Sand Dollars	None
STATION 3	1021				Same	Same	Set substations, yellow rock and rod.	Sand Dollars	None
STATION 4		EBB	FIRST DIVE AT THIS STATION WAS ABORTED						
FIRST TEST RELEASE	1108	1042							
STATION 1	1227		1 2	+0.2 inches +0.5 inches	Visibility somewhat reduced.	Sediment less compacted; penetration 1/2 inch. Ripple marks are present.	Set white rock; marked rod; obtained two core samples.	Same	None
STATION 2			SECOND DIVE AT THIS STATION WAS ABORTED						
STATION 3	1342		1 2	+1.8 inches +2.2 inches	Same	Sediment somewhat less compacted	Set white rock; marked rod; obtained two core samples	A colony of Siphonphores were passing through area. No samples taken.	None
STATION 4	1304					Same	Set substations, white rock & rod.	Same	None
SECOND TEST RELEASE	1427								
STATION 1	1511	SLACK 1514	1 2	+1.1 inches +1.4 inches	The visibility was somewhat reduced and is partially attributable to weather and time of day.	Same	Obtained two core samples and a 3 liter grab sample.	Sand Dollars, some scattered but majority grouped 7/ft^2	None
STATION 2	1457		1 2	+2.5 inches +3.2 inches	Light surge near bottom; strong surface current.	Same	Obtained two core samples; marked rod; and recovered rod and pan.	Sand Dollars	None
STATION 3	1544		1	+2.7 inches	Slight surge near bottom, negligible bottom current.	Same	Obtained one core sample	Free floating siphonphores (unidentified) density 3-4/ft^3	None
STATION 4	1558	FLOOD 1825	1	+0.5 inches	Same	Same	Obtained one core sample.	Sand Dollars	None



CURRENT VELOCITY

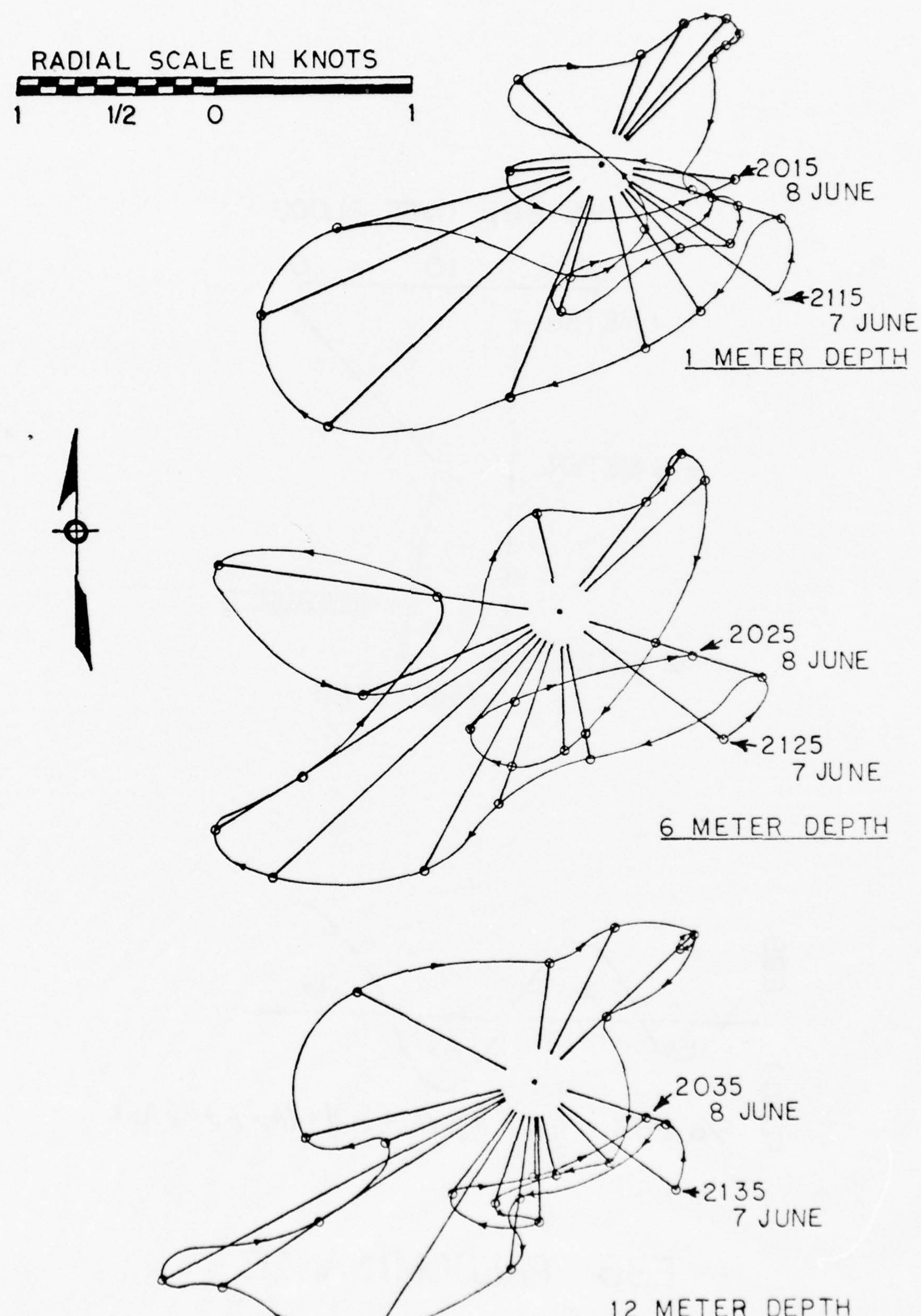
FIGURE 8

The maximum recorded current on 7-8 June was 2.1 knots during ebb flow at a depth of 12 meters and on 8 and 9 February was 2.3 knots on the surface. The final report on current studies by Towill, Inc. can be found in Inclosure 3.

Current measurements by the Corps on 8-9 February and by Brown and Caldwell (Ref. 18) show that during the winter season there is a dramatic difference between currents at the surface and currents a few feet below. The difference may be as much as 2 knots or may be reversed between the surface and a depth of 15 feet. This is the typical current circulation of a positive estuary during the winter months where a thin surface layer of low salinity and density water moves rapidly and almost continuously westward and a higher salinity and density water near the bottom moves into the Bay. U.S. Geological Survey studies (Ref. 19) using seabed drifters have also observed the bottom flood predominance on San Francisco Bar. Brown and Caldwell have found that the basic mass water movement pattern during the winter season is to the westward and southward during ebb flows and to the eastward during the flood with water first moving into the Golden Gate from the north around Point Bonita and from the south around Point Lobos. The effect of the tidal flow extends as far as 15 miles to the west and 10 miles to the south of the Golden Gate. Within this area there is very little evidence that oceanographic currents exert any significant effect on mass water movement.

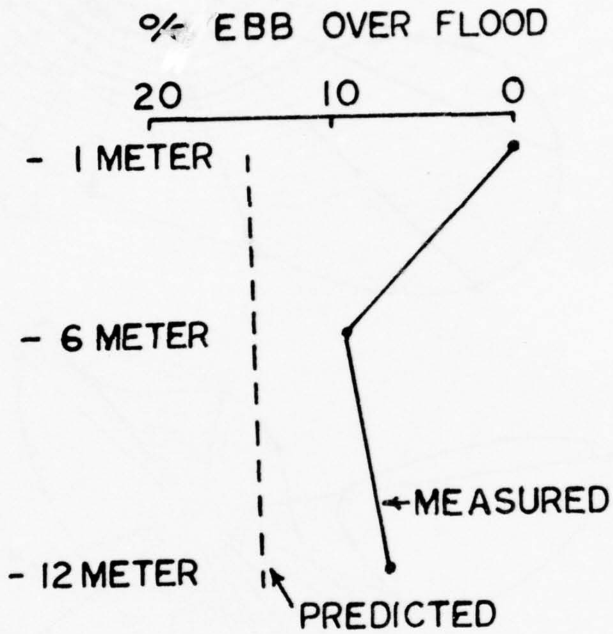
The 7-8 June current measurements represent the typical summer and fall current circulation. Figure 9 shows the current rose plots for the three depths on 7-8 June. The currents at the three depths were fairly homogenous with maximum ebb velocities at times exceeding two knots. As found during the winter season, the currents at all depths exhibited a southwestward predominance and were definitely rotational. It was found that even during the summer season there was a predominating influence of tidal ebb currents. The ebb predominance on 7-8 June shown on Figure 10 increased from 0 percent at one meter below the surface to nearly 10 percent at six meters, then decreased to near 8 percent at 12 meters. The distribution of the ebb predominance during 7-8 June, therefore, was just the opposite of that during the winter months where the ebb predominance occurs in the surface water and flood predominance occurs near the bottom.

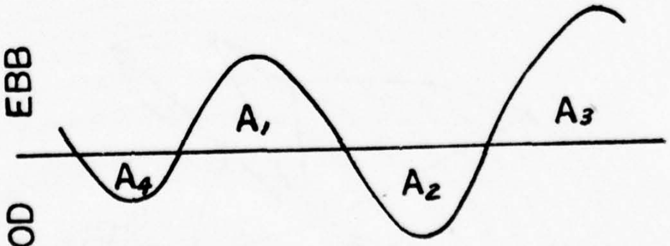
Current path studies using free-floating drogues shown in Figure 11 were made on four occasions. The movement of the current drogues represent the path followed by a given unit of water. The current drogue releases on the four occasions were made at the same location in the Main Ship Channel at a depth of 15 feet. The drogues were released under similar tidal conditions, as shown on Figure 12, and were tracked for periods up to 48 hours. The path studies were scheduled to represent the



CURRENT ROSE

FIGURE 9

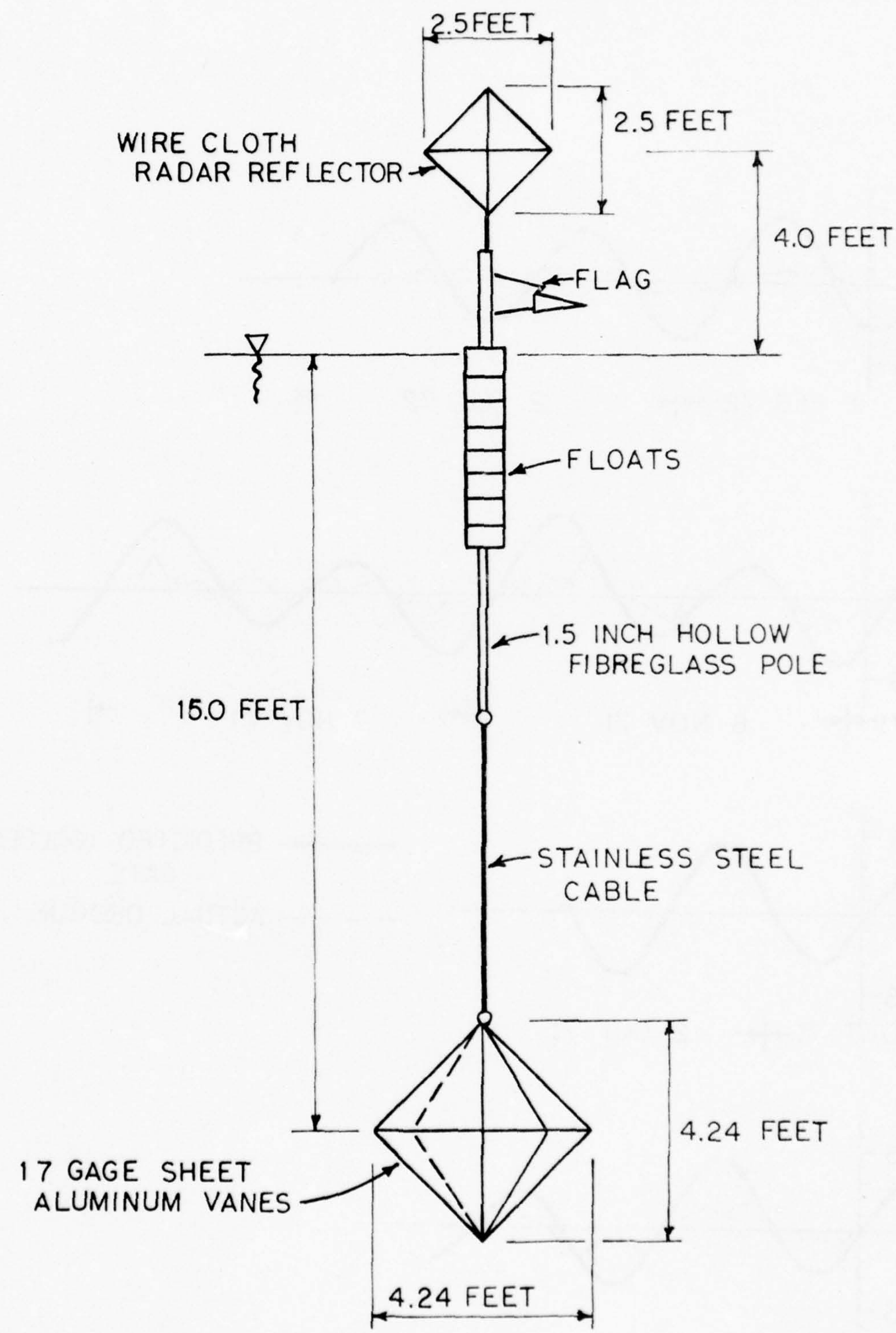




$$\% \text{ EBB} = [(A_1 + A_3) - (A_2 + A_4)] \div (A_1 + A_2 + A_3 + A_4)$$

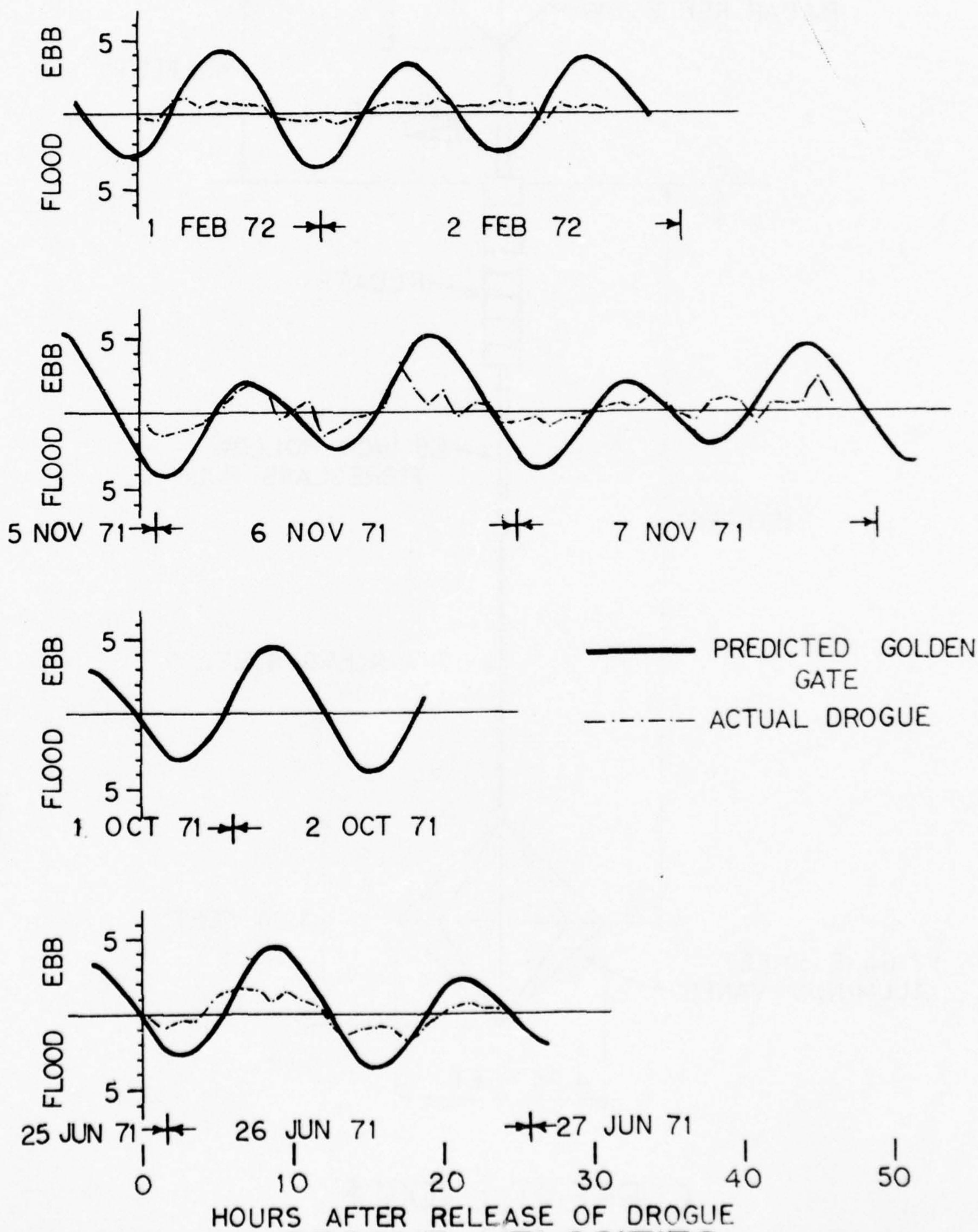
EBB PREDOMINANCE

FIGURE 10



CURRENT DROGUE

FIGURE 11



DROGUE VELOCITIES

FIGURE 12.17

three oceanographic seasons and were conducted as shown in Table 9. The 1-2 October release was terminated after 10 hours due to a breakdown in tracking equipment. The plotted drogue paths for the other three occasions are shown on Figure 13.

The drogue releases were made near maximum floodflows at the Golden Gate (Figure 12). The initial movement of the drogues as shown on Figure 13 on the three occasions was toward the Golden Gate and is associated with the flood tidal flows. The distance of movement toward the Golden Gate on the June and November releases appear to be related to the predicted flood current durations and velocities at the Golden Gate. Thus, in November when the maximum flood current velocity was near five knots with approximately the same duraton as the June path study the drogue moved into the entrance to the Golden Gate. The initial movement of the drogue in February 1972 towards the Golden Gate was very slight. The flood current velocity during the February study was similar to the June study but was of a shorter duration.

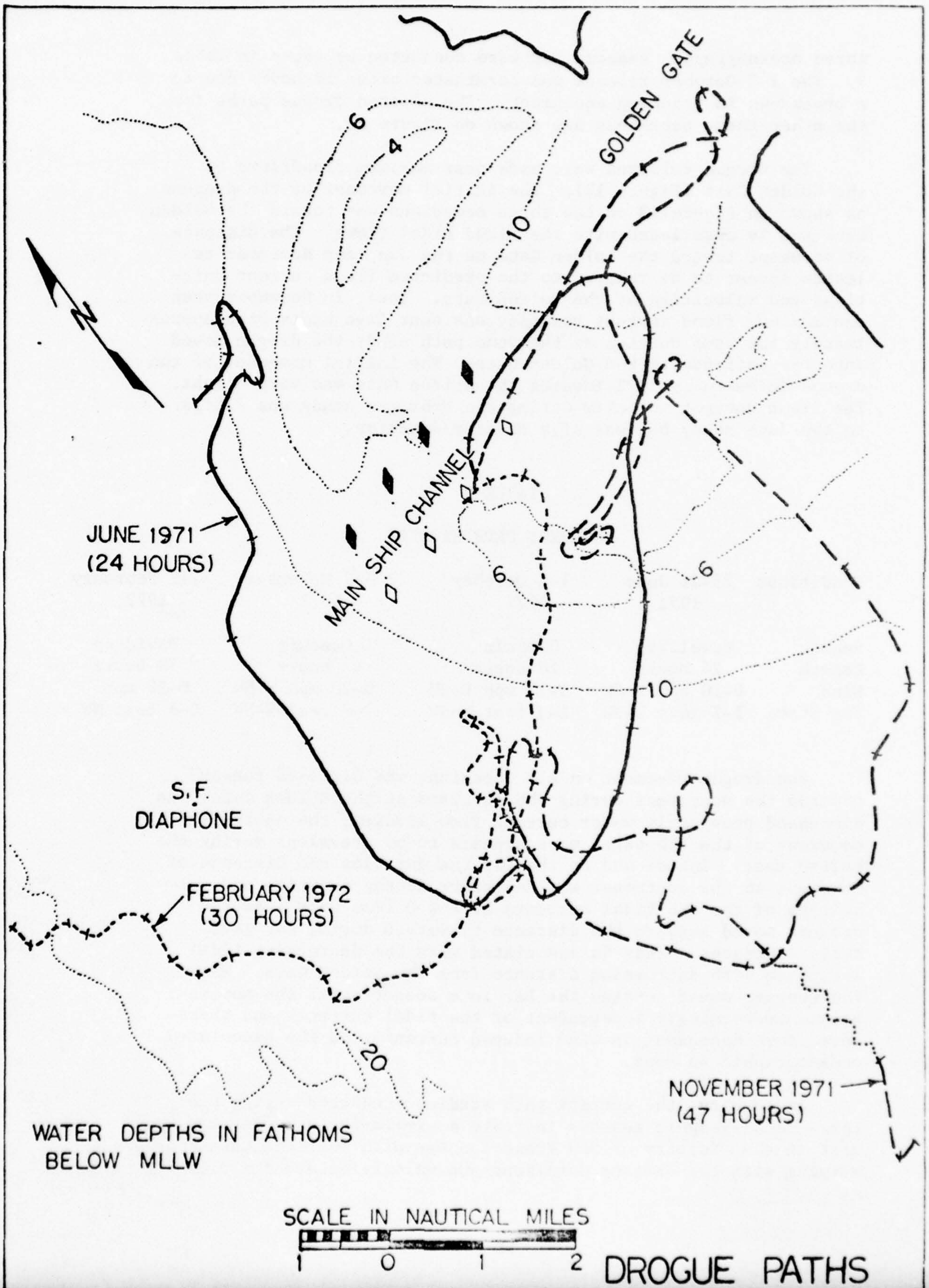
TABLE 9

CURRENT PATH STUDIES

Conditions	25-26 June 1971	1-2 October 1971	5-7 November 1971	1-2 February 1972
Season	Upwelling	Oceanic	Oceanic	Davidson
Length	24 hours	10 hours	47 hours	30 hours
Wind	0-10 mph W-SW	5-15 mph W-NW	0-20 mph N-NW	0-20 mph
Sea State	1-2 feet W-SW	1-3 feet W-NW	1-6 feet W-NW	0-6 feet NW

The drogue movement on all occasions was directed seaward towards the southwest during ebb currents at the Golden Gate. As discussed previously under current flow studies, the southwest movement of the ebb water mass appears to be prevalent during the entire year. Inside and on the Bar the duration and distance of movement to the southwest was dependent on the duration and velocities of the ebb tidal currents at the Golden Gate. As the drogues moved seaward the distance traversed during any tidal cycle decreased. This is associated with the decreasing tidal influence with increasing distance from the Golden Gate. When the drogues moved outside the Bar into deeper water the movement became increasingly independent of the tidal currents and therefore, more dependent on wind induced currents and the associated oceanographic seasons.

In summary, the current path studies conducted during the three oceanographic seasons indicate a similarity of water movement in the vicinity of San Francisco Bar with only the magnitude varying with the current durations and velocities and the time



DROGUE PATHS

FIGURE 13

of year. In all cases with the drogue release on a flooding tide, the initial movement was easterly towards the Golden Gate, thence, southerly and westerly in a clockwise pattern. The studies have also shown that the water movement inside the Bar and on the Bar is primarily dependent on tidal currents and that this influence decreases with increasing distance from the Golden Gate until outside the Bar the primary forces acting on water movement are due to the wind induced and oceanographic currents. There is also an apparent net offshore movement of surface water to a depth of at least 15 feet exiting from San Francisco Bay.

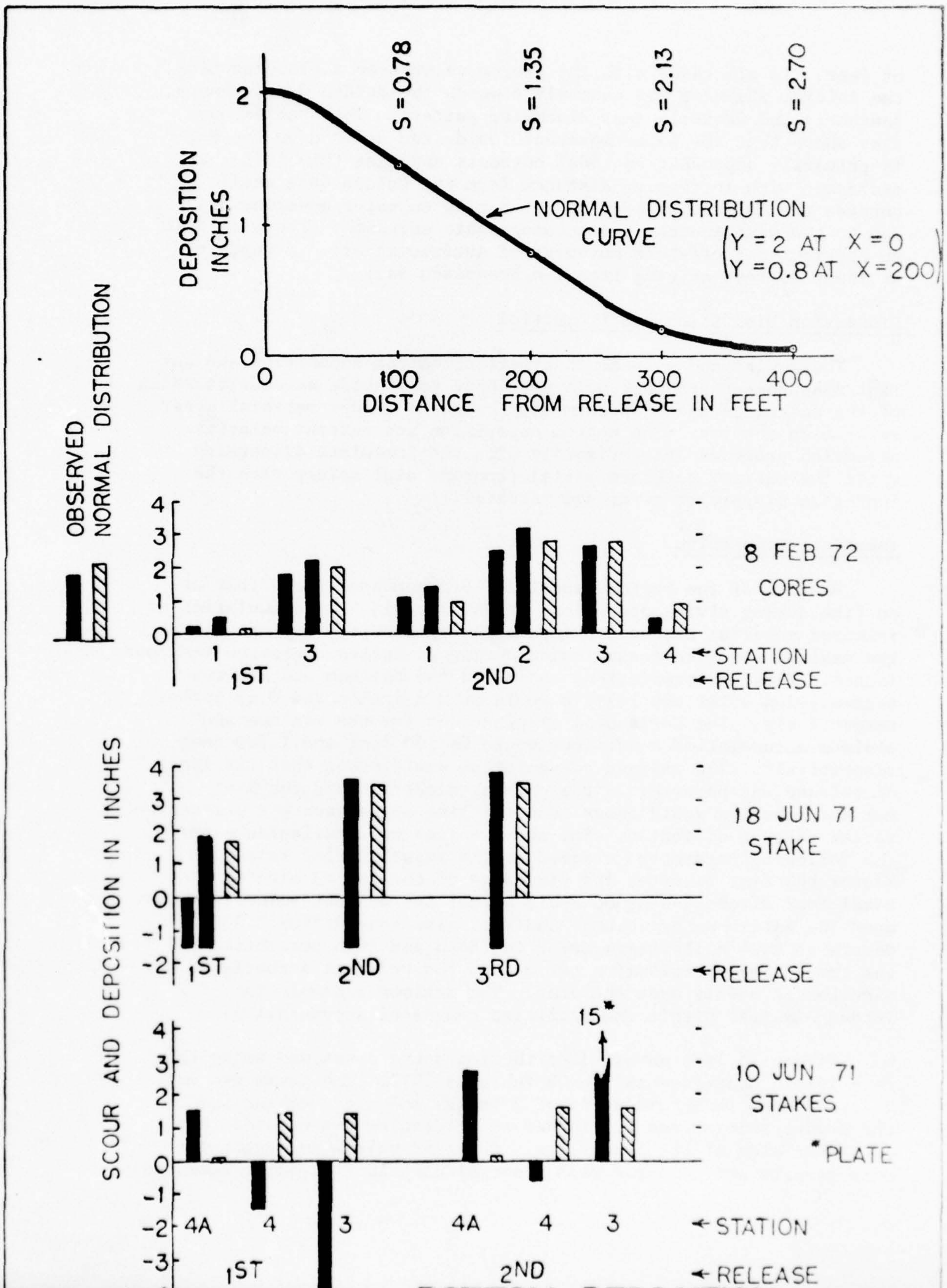
Dispersion Discussion and Evaluation

The aerial and surface observation, bottom deposition and current measurement programs were developed to provide an understanding of the immediate and long-term dispersion of dredge material after release on the Bar. The bottom deposition and current velocity-direction programs deal primarily with the immediate dispersion while the current path and aerial programs deal mainly with the long-term dispersion of dredge material.

Immediate Dispersion

Results of the bottom deposition program have shown that at no time during diving operations on the Bar did the accumulation of released material exceed two inches in depth during any one release. The maximum recorded accumulation during an entire operation was four inches. Prestudy predictions estimated the maximum and minimum accumulation after one release would be 2.5 inches and 0.25 inches, respectively. The horizontal displacement for the maximum and minimum accumulation conditions would be 100 feet and 1,700 feet, respectively. The maximum accumulation would occur when the line of release was parallel to the current direction and the minimum accumulation would occur when the line of release was perpendicular to the current direction. The above values were estimated using the following parameters: speed of the vessel during release-4 knots: the time required for discharge of the load-5 minutes: the total load discharged-3,000 cubic yards: the current velocity-1 knot over the entire water column: sediment size ranged from 0.22 millimeters to 0.84 millimeters using the 84th and 16th percentiles of the cumulative distribution curve: and the sediment accumulated was distributed evenly over the area. The maximum accumulation of 2 inches did fall within the predicted ranges of accumulation.

Figure 14 is a normal distribution curve developed using the core sample measurements from 8 February 1972. The curve was calculated using an accumulation of 2 inches under the centerline of the dredge release and 0.8 inches at a location two hundred feet on either side of the centerline. Observed values for the three sets of data are compared with a normal distribution value based on



BOTTOM DEPOSITION

position of the release to the particular station. The normal distribution readings are 96 percent and 93 percent of the observed accumulation values for 8 February 1972 and 18 June 1971, respectively. These percentages exceed any expected accuracy of predicted accumulation values for the Bar under prevailing conditions. Other measurements made on 18 June 1971 (not included in the above percentages) indicated the occurrence of about 1.5 inches of scour around the stake during the entire testing period.

No correlation has been found between the observations on 10 June 1971 and the above analysis. Of six observations on 10 June 1971, three indicated only scour ranging from 0.6 inches to 4.7 inches whereas observations on 18 June indicated a consistent scour of 1.5 inches. The three remaining observations indicated only accumulation whereas all observation on 18 June indicated accumulation and scour. The stations indicating accumulation on 10 June were all up current from the release whereas the stations indicating only scour were either near the line of release or were down current. For these reasons the deposition and scour data for 10 June 1971 have been disregarded. Some factors contributing to the decision are: (1) local scour around stakes was not accounted for in measuring accumulation; (2) divers were unfamiliar with stake gradation marks: and, (3) sea state and visibility hindered diver operations. Furthermore, one observation on 10 June indicated an accumulation of 15 inches. This was the last observation of the day and the diver reported excessive turbidity due to sea state. The diver made the 15-inch accumulation observation from the plate rod and not the stake as was done from all other observations since the stake could not be located. When the diver returned to recover the stake and plate, neither could be located.

The horizontal movement of suspended dredge material and the subsequent dispersion of material after deposition can be described as the vector sum of the tidal currents, wind induced currents, coastal currents and wave induced turbulence (surge). The observed velocity-direction measurements are the sum of the tidal, coastal, and wind induced currents. The wave induced motion near the bottom-water interface is primarily oscillatory in nature and, thus, is mainly a suspending force. The dispersion of the deposited dredge material will be in the direction of the bottom currents as observed during the current velocity-direction measurements.

The current velocity-direction measurements observed on 8 June 1971 are indicative of summer-fall current conditions on the Bar. The currents were fairly homogeneous at all depths and exhibited a definite southwestward predominance. During the winter season with its high freshwater outflows from the Bay, current reversals with depth are encountered on the Bar. A net water discharge occurs in the upper water column during these freshets, whereas in the lower

column a net influx into the Bay of more saline water occurs. Even during the winter season the water circulation on the Bar exhibits a southwestward predominance. It follows then that the dispersion of dredge material on the southern portion of the Bar would initially be directed in the direction of the tidal currents as observed from velocity-direction measurements. Thus, if dredge material release operations are conducted during ebb flows, the initial dispersion would be away from the Golden Gate in a southwestward direction. Conversely, the initial movement of released material during flood flows would be towards the Golden Gate.

The bottom deposition program has shown that accumulation of dredge material on the bottom does not exceed two inches during any one release and that after deposition the material is dispersed quickly as a result of the suspending wave induced turbulence and the transporting bottom currents. The current velocity-direction program indicated that the dredge material while in the water column and after deposition will have a net dispersion directed to the southwest.

During diving operations four distinguishable sediment layers in the water-sediment column shown on Figure 15 were observed. They were the upper water column extending from 25 to 35 feet below the sea surface, the turbid layer extending 3 to 15 feet above the bottom, the fluid sediment layer 3 to 6 inches deep on the bottom, and the underlying compacted sediment.

The turbid and fluid sediment layers were found to be the transport strata for material on the Bar. The turbid layer was composed of suspended sediment, moving horizontally along the water-bottom interface. It was observed before, during and after all test releases throughout the entire study. The depth and sediment concentration of the turbid layer was found to be a function of current velocities and sea state. As the currents and sea state increased, the depth of the layer and concentration of sediment in the layer increased. The maximum and minimum depth encountered during the study were 15 feet and 3 feet, respectively. The minimum conditions existed during calm seas with only slight bottom currents. Water samples in the turbid layer showed the presence of considerable suspended sand in the 200-275 micron range, the same range as that found in the fluid and compacted sediment layters. The fluid sediment layer was composed of uncompacted sand moving as bed load. It was observed to be absent during calm conditions with a more compacted layer of sediment existing in its place. As the sea state became more active the fluid layer again appeared.

The minimum condition of sediment transport that existed on the Bar during the study was in the more advanced stage of sediment motion as described by Shepard (Ref. 20) from observations in a simple flume. Shepard's advanced stage of sediment transport consists of both bed load and suspended load transport of sediment. The sediment

that is transported by bedload is moved by saltation and is associated with the formation of ripple marks. The sediment transported by suspended load is put into suspension by turbulence over the bed and is associated with a high Reynolds' number which is a function of height above the bed, the flow over the bed and the viscosity of the water. Large Reynolds' numbers are always present in an environment such as San Francisco Bar and are mainly associated with stresses due to sea state and internal waves (surge). Although the Reynolds' number due to current flow is sufficient to maintain the suspended load in the turbid layer, the major component of turbulence is due to the activity of the surface waves and the existing surge. The major suspending force on the Bar is the wave induced turbulence. Tidal flows are responsible for net horizontal movement on and within the Bar. At all times during the study the wave induced turbulence was great enough to keep material in suspension. The turbid conditions precluded the actual observations of bedload transport of sediment: however, ripple marks with a wave height of 1-1/2 inches and wave length of 4 inches indicated that such a transport was occurring.

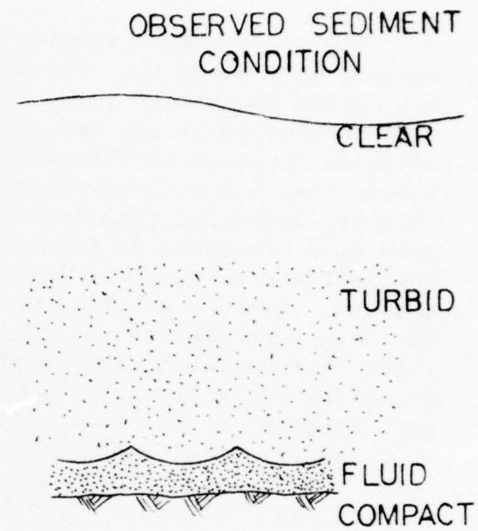


FIGURE 15

The condition of greatest sediment transport during the study was observed during increased sea state and surge action. The presence of a thick turbid layer and a fluid sediment layer indicates the existence of Shepard's maximum condition of both a large suspended load and sheet flow. Due to the turbulence on the Bar, there is no threshold velocity associated with the sediment transport.

Long-Term Dispersion

The net long-term dispersion of dredge material is a function of the forces acting on the medium in which the material has been introduced. The forces in this case are the various currents induced by tidal, wave, wind, and other generating phenomenon causing the movement of the water mass. The net movement of the water mass, as measured with the current path program, then is an approximation of the sum of the forces acting on the water. Assuming the water column is uniform, the direction of net movement of dredge material can be approximated by the direction of the net movement of the water mass.

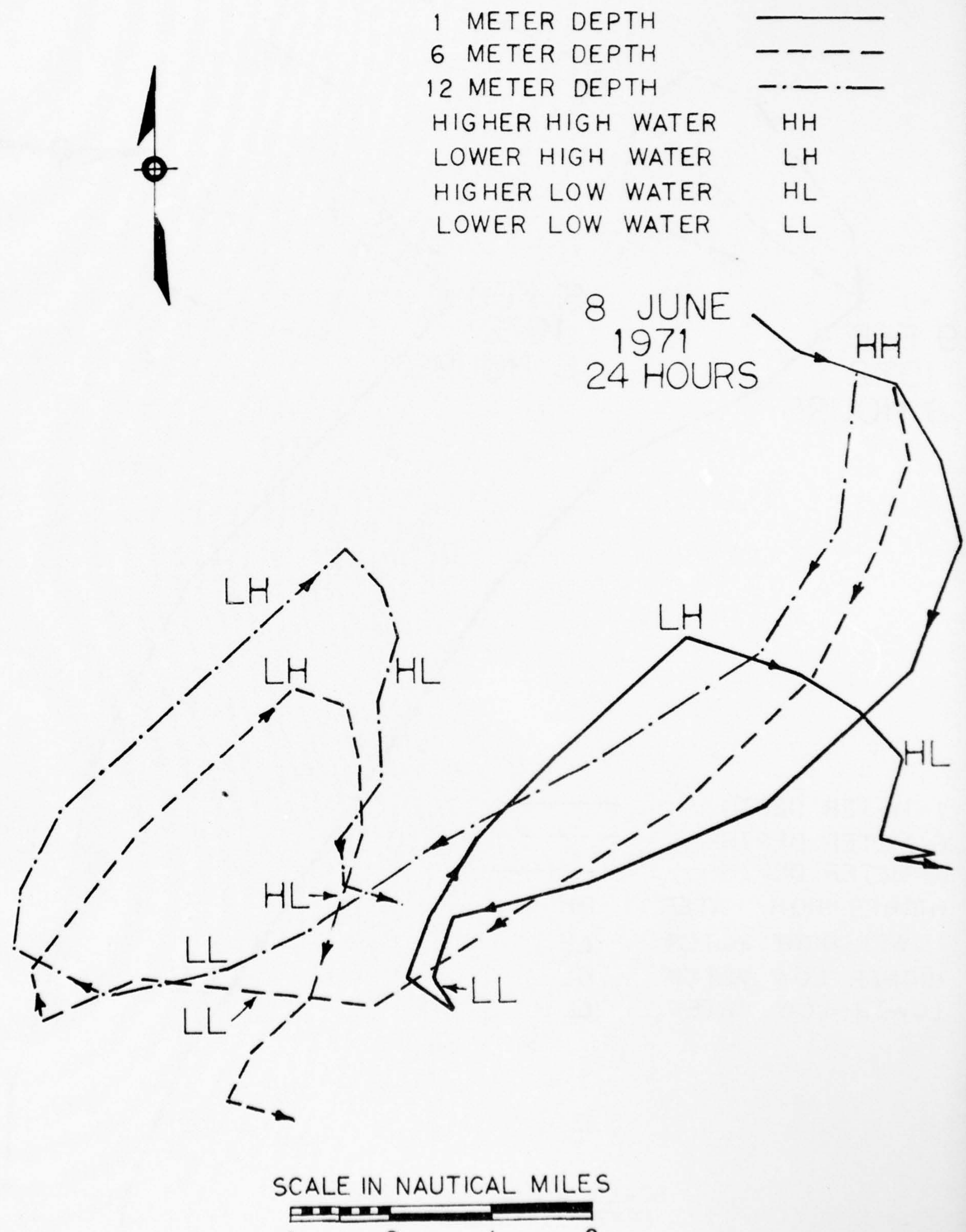
The current path studies conducted during the three oceanographic seasons have shown that the mass water movement near San Francisco Bar during the entire year, is similar with only the magnitude varying with current durations and velocities. In all cases there was a net offshore movement to the southwest similar to that observed during the current velocity-direction program. Vector plots of the current velocity-direction data in terms of the spatial scale of the current path plot are shown in Figures 16 and 17. The vector plots are hypothetical and assume that the current patterns on the entire Bar are uniform. Because of this, no hydrography or reference points on the Bar have been plotted, since it cannot be assumed that a particle of water follows the indicated plots. However, when comparable times in the tidal cycle are super-imposed, a comparison of the current flow and path studies can be made. Although there is no direct correlation as to magnitude of mass water movement and long-term sediment movement, one can infer that the net dispersion of dredge material on the southern portion of San Francisco Bar would be directed to the southwest and that the dredge material will not re-enter the dredge channel nor be transported into the Golden Gate. Initial movement of the dredge material when released during floodflows 3,000 feet south of the channel would be directed toward the Main Ship Channel and the Golden Gate. To prevent the material from re-entering the channel, the release of material has been shifted 6,000 feet south of the channel.

BENTHIC STUDY

Program

The objectives of the benthic study were (a) to develop a faunal list, (b) characterize those species found as to their susceptibility to smothering and (c) determine if there was a significant difference in the number of species and/or number of individuals before and after dredging and disposal operations. The program involved (1) a survey of the benthos using a bottom dredge, (2) diver observations of benthic fauna and (3) laboratory experiments investigating the phenomena of smothering.

The first step in investigating the effects of disturbing the benthic ecosystem was to reconnoiter the inhabitants of that environment, determining the composition of the population and their numbers. This examination was to proceed in a quantitative and a qualitative manner. The quantitative approach involved a benthic survey or collection program prior to and following each dredging operation. It was to employ a Petersen bottom dredge to obtain samples of the biological populations present in each study area. The qualitative program was based on diver observations. Except for two days of diving in September 1972, the main thrust of the diver program was to determine the depth of sediment deposition following the disposal operation. These studies were discussed in the Material Dispersion section.



CURRENT VECTOR

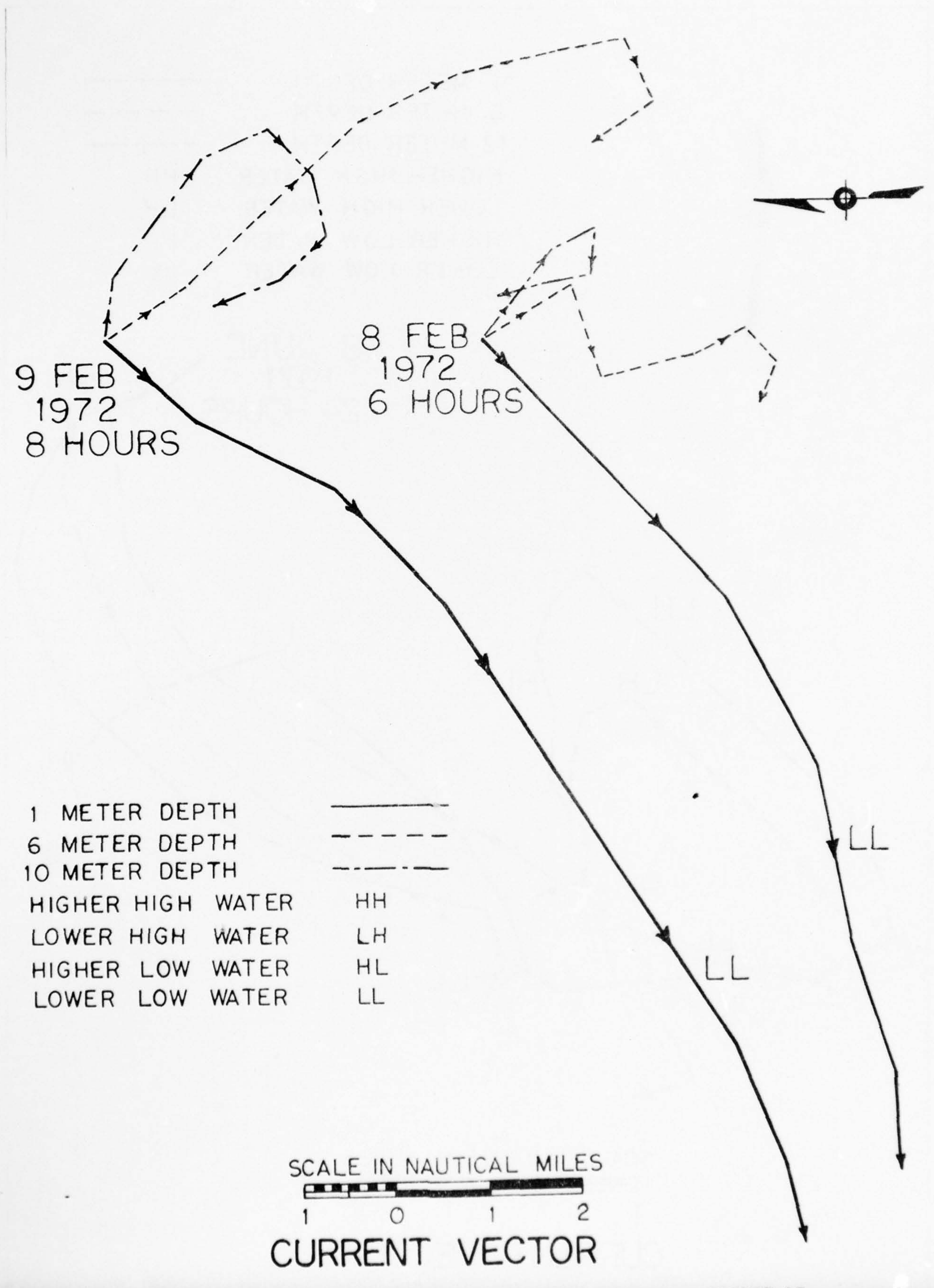

9 FEB
1972
8 HOURS
8 FEB
1972
6 HOURS
LL
LL
1 METER DEPTH
6 METER DEPTH
10 METER DEPTH
HIGHER HIGH WATER HH
LOWER HIGH WATER LH
HIGHER LOW WATER HL
LOWER LOW WATER LL
SCALE IN NAUTICAL MILES
1 0 1 2
CURRENT VECTOR

FIGURE 17

Test Operations and Results

a. Benthic Survey. Design of the benthic survey entailed the selection of sampling stations, development of collection methods and procedures, and formulation of a statistical approach to enable analysis of the data.

The Main Ship Channel, as has been explained, is a 3-mile long channel cut through the outwardly curved Bar. Sediment samples taken from the Channel indicate that the material is not uniform in size. The mean particle size varies from a coarse grain sediment on the west end to a fine grain sediment on the east. An increase in amount of organic material can be correlated with the increasing fine content of the sediment of the channel. The organic material consisted of shell fragments with associated organic debris and vegetable matter normally in the form of finely divided black detritus. Because of this variation in bottom substrate, sampling locations were selected at each end of the channel as shown on Figure 4. The first location or station was positioned mid-channel between buoys 1-2 and 3-4 and the second mid-channel between buoys 5-6 and 7-8. The work of Ebert and Cordier (Ref. 21) and Yancy and Wilde (Ref. 22) was used as the basis for sampling location selection in the disposal areas on the San Francisco Bar. Ebert and Cordier reported coarse sediments containing abundant shell fragments and a negligible infauna. Yancy and Wilde found that the Bar material was a medium grain sediment whereas the material outside in the Gulf of the Farallones was fine-grained sediment. Each area had well developed infauna populations. Ignoring the dissimilarities in the techniques used in the two studies, the sediment and infauna data indicates three unique areas associated with the Bar: the area inside the Bar, the Bar itself and the area outside the Bar, i.e., in the Gulf. On this basis, a station was selected in each of the areas. A sampling program was designed utilizing five locations, two in the Ship Channel and three in the disposal site. Each location was outlined by a square 2,000 feet on a side. The outline of each square was delineated in terms of "uniform habitat," that is, relatively uniform depth, homogeneous particle size and organic content, and similarity of degree of wave and current induced disturbance. The staion locations are shown on Figure 4. There are two sets of three stations in the disposal area. The three stations closest to the channel were used in 1971 when the disposal area was situated approximately three thousand feet south of the channel. In 1972, the disposal area was moved three thousand feet further south with adjustment of the sampling stations.

Past experience and communications with persons who had worked in the area suggested sampling by bottom grab was more practical and safer in the Bar area than diver sampling. Therefore utilizing the sampling squares as stations, a program to take random bottom grabs in each of the squares from unanchored positions was selected. One reason for this approach was it alleviated the difficulty of finding fixed positions in the open ocean, fixing and holding those

positions while trying to anchor in the turbulent waters associated with the Bar. Secondly, it eliminated the problem of possible interference with ship traffic in the channel. Finally, random sampling inside these squares reduced bias caused by clustering or non-uniform distributions of the organisms within the areas. Within each square area, a composite sample consisting of two random grabs was collected. The composite was homogenized and a one liter aliquot taken. The aliquot was screened "on board" through a size 30 sieve (0.595 mm mesh) and the organisms pickled using a 10 percent formaldehyde - 90 percent seawater solution for later sorting, identification and enumeration.

The first two collections prior to and following the 30 June to 30 July dredging were obtained using a Petersen bottom dredge, 0.12 square meter, with a full capacity of eleven liters. The dredge normally contained only six or seven liters of sediment however. This was the result of the compacted nature of the sand substrate which reduced the depth of penetration and the loss of material as the dredge was pulled up through the water column. The third set of samples was obtained by divers on 27-28 September. The divers were separated into two teams. One team was composed of two biologists from the Department of Fish and Game and the second of two biologists from the San Francisco District of the Corps of Engineers. Two samples were collected at each station, one by each diver on the team. The divers used hand trowels to scoop the sediment into plastic bags. Each bag contained approximately four liters of material. The fourth set of samples was collected on 18 January 1972 with the Petersen bottom dredge. Following the fourth collection, the Petersen was lost at sea. It was replaced with a modified Ponar bottom dredge, 0.05 square meter, with a seven-liter capacity. The dredge normally obtained a sample of only four or five liters even though it was modified for the sand substrate. The modifications to the dredge consisted of adding fifty pounds of weight and removal of the side plates to increase penetration. This dredge was used to collect samples on 19 April and 11 May 1972. The sampling results are presented in Table 10.

The sampling program was not quantitative and cannot be used for cause-effect relationships because of the many constraints placed on the conduct of the program. Control sites which are essential for determining the difference between normal seasonal variations in species composition and variations resulting from the disturbance of the species caused by the operation were not included. The absence of replicate samples negates evaluation of the degree of success of the sampler in obtaining representative samples of the benthos. Diver collected samples were substituted for dredge samples during the third sampling period. Following the fourth sampling period when the Petersen dredge was lost, a Ponar dredge which differed from the Petersen with respect to area sampled, capacity and depth of penetration, was used. No analysis was performed to determine

TABLE 10

FAUNA LIST AND SAMPLING RESULTS

ORGANISM: DATE:	4 June 71					25 Aug 71					27-28 Sep 71					18 Jan 72					19 Apr 72					11 May 72				
AREA:	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Coelenterata																														
Polyorchis penicillatus																4		1			3		2			4	2	1		
Annelida																														
Polychaeta	2	2	1	3	1	2	6	1	14	18	3	3	9	37	6	2	1	1	13	12	2	4	1	8	4	1	1		13	14
Oligachaeta							1		1		1	1		7	2					2						1			2	1
Arthropoda																														
Ampithoë sp.					1												1											1		
Balanus improvisus											42				50															
Bet. aeus setosus	4	1			3		5			6											1			3		2			1	1
Blepharipoda occidentalis								1										2												
Cancer gracilis															1		1													
Cancer magister		1																			1									
Cancer productus																		1										1		
Crago franciscorum																			1							1				
Cumella sp.				18	13		10		20	26	2			74	5				18	14		4		36	17				12	6
Holopagurus pilosus											5		4		4	1				1			2	1	3		1		2	
Janiralata davisi	1		1																							1				
Ostracoda																								1						
Synidotca ritteri										3																				
Mollusca																														
Cadulus californicus									1																					
Cardium corbis											1			1											1					
Nassarius fossata	2	2			1	3	1			1			1	2								2		1			1	1	2	
Olivella biplicata	6	1				2		1									1				1		1				2			
Olivella pycna	14	3	4	9	1	5	31	1	3	5	2			6	2	3	1		2	3	1	4		2	4	3	1	2	4	6
Siliqua patula														2				1												1
Tellina bodegensis								1						1					1					1					1	
Tellina salmonea					1				1			1	1																1	
Echinodermata																														
Amphiphalis pugetana										1														1						
Dendraster excentricus	8	3		3	2	1			3		3			3		2	3	2		3		1		3	2	6	3		1	

the sampling characteristics of the three methods. The volume of the samples collected for comparison of number of individuals per liter was not measured. Further, the disposal site was changed from first to the second year with required sampling occurring in different seasons. Comparison of abundance and type species between the two years is questionable. Finally, species identification of polycheata and oligocheata was not made. Species were lumped to obtain total number of individuals only. This reduces the value of the data because of the importance of these Classes as indicators of disturbance by changes in species composition.

Aware of these deficiencies, numerical reduction was performed to attempt interpretation of the data in a qualitative manner. The number of individuals, number of species and number of phyla are tabulated in Table 11 and are graphically presented in Figures 18 and 19. The number of species and average number of species do not include the polycheata or oligocheata populations. Additionally, average number of species, individuals and phyla are tabulated in Table 12. The number of species, number of individuals, average number of species and average number of individuals exclude the barnacle (B. improvisus) population data. The barnacle populations were attached to single rocks which had moved into the sampling area and are not representative of the normal benthic community found on the Bar. Therefore, their fortuitous collection was not included in the calculations.

Evaluation of trends in the data using Figures 18 and 19, indicate that dredging and disposal have different effects on the Bar environment. In the months following dredging operations in the channel, Station 4 particularly showed increases in the number of individuals and species both in 1971 and 1972. Station 5 initially showed increases in the number of individuals in 1971 and increases in the number of species in 1972 but by the second post-dredging sampling had dropped below predredging levels in both number of individuals and species in both years. The removal of organisms from the dredged area opens niches which seem to be quickly filled by "opportunistic" organisms from adjacent areas. This migration initially causes the number of species and individuals to increase above predredging levels; then, as competition increases, abundance returns to pre-disturbance levels.

The disposal operation effects vary with the area investigated. The area outside (Station 1) and inside (Station 3) the Bar responded in a similar manner each year. These two areas showed a decrease in number of individuals following disposal operations; however, the number of species remained fairly stable. This seems to indicate that there is a certain degree of smothering but that species composition remains stable. Station 2, in the middle of the disposal area, showed increases in the number of individuals but decreases in the

TABLE 11

Changes in Numbers as a Function of Time

Number of Individuals

Sampling Station	1	2	3	4	5
4 Jun 71	37	13	6	33	23
25 Aug 71	13	54	5	43	54
28 Sep 71	17	8	15	133	20
18 Jan 72	12	8	8	35	35
19 Apr 72	9	15	6	57	31
11 May 72	19	8	6	39	29

Number of Species

Sampling Station	1	2	3	4	5
4 Jun 71	6	6	2	3	7
25 Aug 71	4	4	4	5	6
28 Sep 71	5	2	3	7	4
18 Jan 72	4	5	5	4	4
19 Apr 72	5	4	3	9	5
11 May 72	6	6	5	8	4

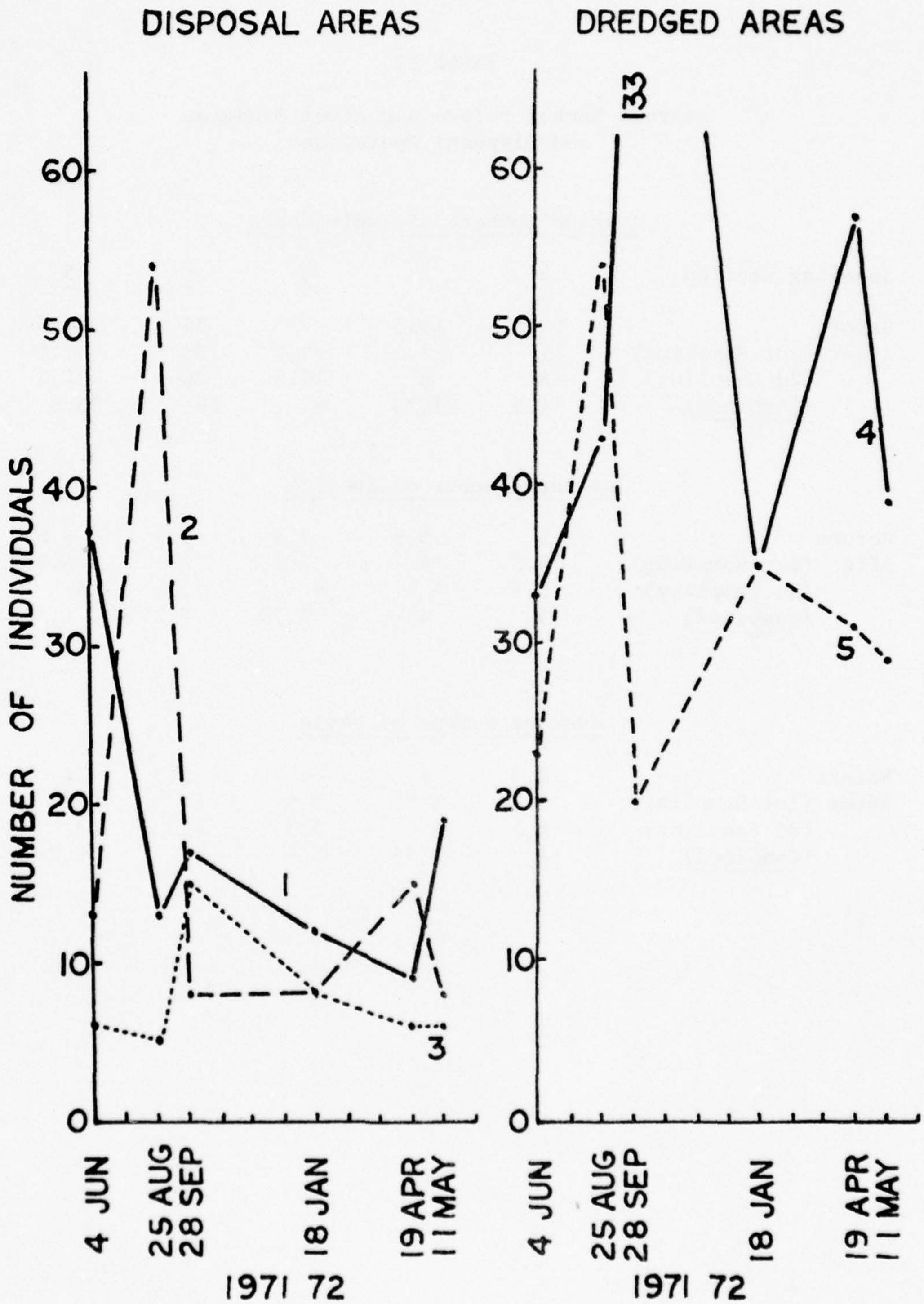
Number of Phyla

Sampling Station	1	2	3	4	5
4 Jun 71	4	4	3	4	4
25 Aug 71	3	3	3	4	3
28 Sep 71	4	3	3	4	3
18 Jan 72	5	4	5	3	4
19 Apr 72	4	4	4	4	4
11 May 72	5	5	4	4	3

TABLE 12

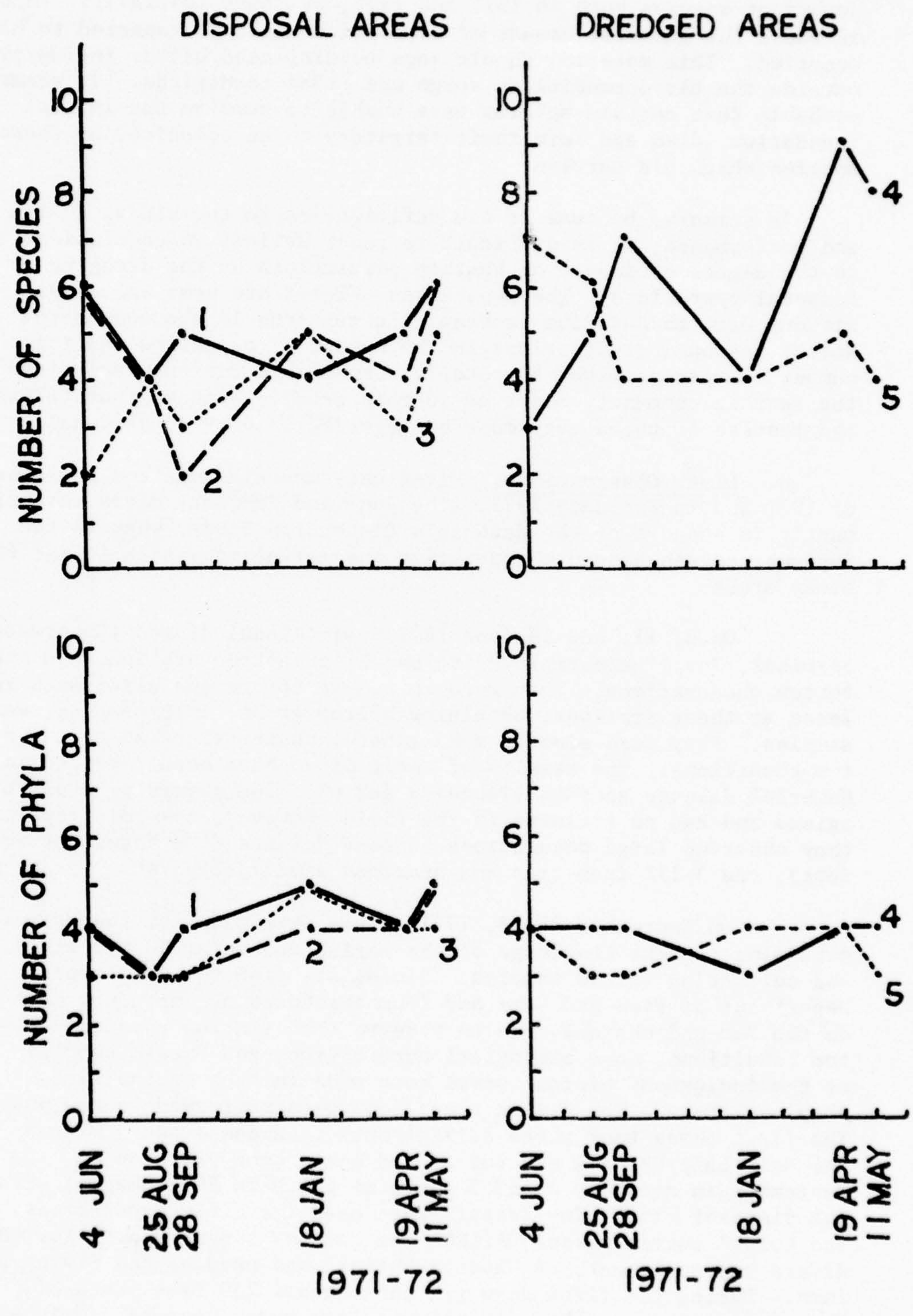
Average Number Before and After Dredging
and Disposal Operations

Sampling Station	1	2	3	4	5
Average Numbers of Individuals					
Before	24.5	10.5	7	34	21.5
After (1st Sampling)	11	34.5	5.5	50	42.5
(2d Sampling)	18	8	10.5	86	24.5
(Combined) / 2	14.5	21.25	8	68	33.5
Average Number of Species					
Before	5	5.5	3.5	3.5	6.5
After (1st Sampling)	4.5	4	3.5	7	6.5
(2d Sampling)	5.5	4	4	7.5	4
(Combined) / 2	5	4	3.75	7.25	5.5
Average Number of Phyla					
Before	4.5	4	4	3.5	4
After (1st Sampling)	3.5	3.5	3.5	4	3.5
(2d Sampling)	4.5	4	3.5	4	3
(Combined) / 2	4	3.75	3.5	4	3.25



BIOLOGICAL SAMPLES
SAN FRANCISCO BAR

FIGURE 18



BIOLOGICAL SAMPLES
SAN FRANCISCO BAR

number of species both in 1971 and 1972, at least initially. This is where the greatest amount of deposition would be expected to have occurred. This material should soon be displaced either inside or outside the Bar depending on surge and tidal conditions. It seems probable that certain species were unable to survive the initial inundation, died and left their territory to be colonized by those species which did survive.

In summary, because of the deficiencies in the study, design and performance, it is difficult to reach definitive conclusions as to the degree of impact on benthic populations by the dredging or disposal operations. The hypotheses offered are near valueless without data to describe seasonal fluctuations in the community. Normal seasonal fluctuations in the number of organisms and the number of species might be totally responsible for the variations in the benthic community observed in this study. Without that information the results of the survey must be regarded as very conditional.

b. Diver Observations. Dives were made in June and September of 1971 and in February 1972. The June and February dives were primarily in support of the Materials Dispersion Study, whereas the September dives helped characterize the marine ecosystem in the five study areas.

On 8, 11, and 18 June 1971 professional divers (Underwater Services, Inc.) were employed to establish bottom stations and make bottom observations. They were to sample before and after each release at these stations, obtaining bottom grabs, core samples, water samples. They were also to make general observations as to the bottom conditions. The results of their dives have been reported in the Material Release section (Tables 5 and 6). The divers were not biologists and had no training in the field; however, they did report that they observed large populations of sand dollars (one dozen per square foot), one 3-1/2 inch crab and numerous small jellyfish.

On September 27-28, 1971, dives were made for the purpose of expanding present knowledge of the marine ecosystem in the study areas and collecting bottom samples. Biologists from the California Department of Fish and Game and from the Corps of Engineers dove on the Bar and channel area to observe the existing physical bottom conditions, make biological observations and obtain samples of the indigenous biota. Dives were made in each of the five sampling areas. The diving operations were performed in two phases. The first phase took place 27 September in areas 4 and 5 within the Main Ship Channel and the second phase took place on 28 September in areas 1, 2 and 3 south of the Main Ship Channel within the disposal site. Two vessels were used for diving operations. The Corps' survey vessel HALLECK was used as a base vessel for the divers and equipment. A "Boston Whaler" was used as the diving platform. During the first dive (in the channel 250 feet south of buoy 3,) neither benthic nor pelagic life were observed. Only some shell fragments and fine white organic material were seen. The anchor

was recovered after the dive and reset about 250 feet into the channel south of buoy 5 and in line with buoys 5 and 6. Two dives were made at this location. No pelagic life was noted but some benthic life was observed. The benthic life seen by the divers included one slender crab (Cancer gracilis), some sand dollars (Dendraster sp), one hermit crab (Pagurus sp) and many polychaete worm tubes. A moderate amount of drift debris along the ridges of sand ripples were noted.

The first diving station on 28 September was located approximately 3,400 feet south of buoy 4 and inline with buoys 3 and 4 in the disposal area. Sand dollars, hermit crabs, several species of snails and one sand dab were among the benthic life observed. No pelagic life was noted at this station. Some shell fragments and leptopel (white organic material) were seen. The second diving station was located 3,000 feet south of buoy 6 and in line with buoys 5 and 6. The benthic life observed included sand dollars, sand dabs, market crabs (Cancer magister), and another species of crab (Cancer productus). Some organic debris were noted on the ridges of sand ripples. No pelagic life was noted by the divers. The third diving location was 3,000 feet south of buoy 8 and in line with buoys 7 and 8. The benthic life observed included a few sand dollars, hermit crabs, sand dabs, large and small snails, worm tubes, and one market crab. No pelagic life was noted.

On 8 February 1972, the final set of dives were made on the Bar again in association with the Material Dispersion Study. Similar to the first dives in June, observations of benthic and pelagic life were made but were not the primary thrust of the operation. One juvenile sand dab, several jellyfish and again numerous sand dollars were reported.

Divers' logs are attached in Inclosure 4.

c. Smothering Experiments. The sand dollar, Dendraster excentricus (Eschscholtz) is one of the most abundant macroinvertebrates in terms of biomass and numbers of individuals on the San Francisco Bar. The divers reported densities as high as 225 individuals/m^2 with average densities of 90 individuals/m^2.

Material dispersion studies indicated the disposal operation caused accumulations of slightly greater than 5 cm. This material obviously inundates all bottom organisms unable to quickly escape by either swimming or running from the area. The sand dollar, Dendraster excentricus (henceforth called Dendraster) is unable to do either and therefore, is covered with the material.

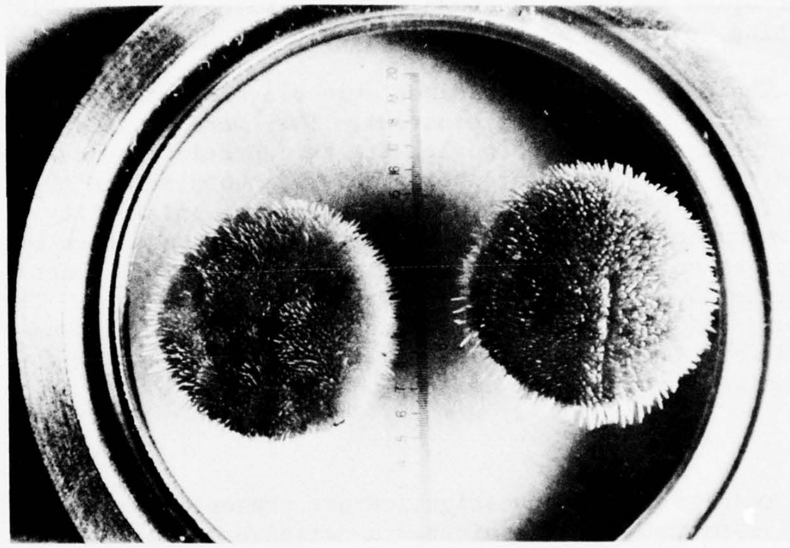
Because of its abundance on the Bar and slow mode of locomotion, Dendraster was chosen for further study to determine organism behavior under sand burial.

Dendraster (Order Clypeastroida, Family Schutellidae) has a very flat, thin-edge, discoidal test covered with numerous minute spines giving the animal a velvety appearance (see photograph 13). The oral surface is flattened and the aboral is convex. The ambulacral areas of the aboral surface form a five-pointed star with the two posterior points being shorter than the other three giving an "excentric" guise (hence the species name). The skeleton is composed of ossicles formed into flattened plates that are fused together to produce a solid immovable test. Each plate bears a large number of round tubercles to which the many small spines are attached. These spines have been shown to be the primary means of locomotion (Ref. 23).

The San Francisco Bar is a constantly shifting sand environment. The divers observed sand ripples about 7 mm high and 60 mm apart. Sand dollars were observed to be in rows parallel with the ripple marks. However, they were not uniformly arranged on the crest or in the trough of the ripples. These rows were 7-14 cm apart with approximately 90 percent of the animals in these rows. The other 10 percent were scattered randomly. The animals were half buried in a uniform oblique position with the oral surface slanting in the direction of the current. This parallel orientation with the current was reported earlier by Reese (Ref. 24) and the oblique position by Hyman (Ref. 25).

Animals were collected on April 19 and May 11, 1972 with the modified Ponar bottom grab which, as previously mentioned, had 50 pounds of extra weight added and the side plates removed. Some animals were badly damaged by the grab and these were discarded. Twelve animals of similar size were collected in April and thirteen in May. The sand dollars ranged in width from 63 to 78 mm with the average size being 70 mm. They were placed in a plastic bucket in about 5 cm of pre-dried sand in April and native material in May. They were covered with 10-12 cm of seawater which was changed every 15 minutes. The organisms were transported to San Francisco State University marine invertebrate laboratory. The animals were randomly separated into two groups. The first group became the controls. They were placed in one of the wall tanks in the laboratory which contained a pan of sand and some sand dollars of another species. The second or experimental group was placed along with the bottom material in a glass aquarium. The aquarium was serviced by the same water and air supply as the controls.

The first set of experimental animals were placed in the observed oblique position, however, after 24 hours of acclimation



ORAL SURFACE - ABORAL SURFACE

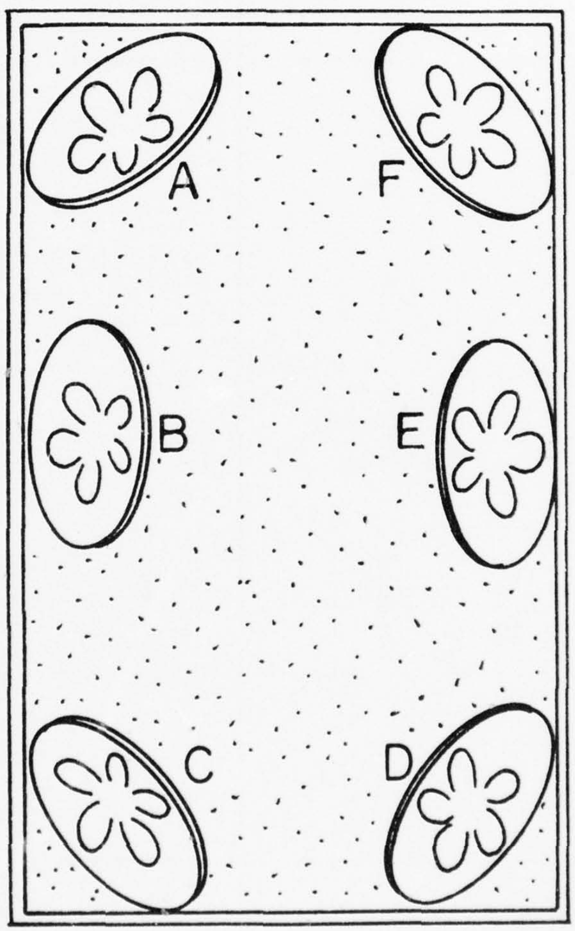
PHOTOGRAPH 13 JUVENILE DENDRASTER EXCENTRICUS (ESCHSCHOLTZ)

they were lying flat or were partially buried in a horizontal position. The day following collection all animals were measured laterally and their general health estimated based on the activity of their spines. A subjective procedure of assigning a numbered value for spine activity was used with "0" being dead and "10" representing as active as when collected.

The experimental organisms were placed in the four corners and on two sides of the aquarium. They were positioned such that they were at about 30° angle with the anterior end against the glass (as shown in Figure 20). This was to simulate their position in the Bar and additionally remove the possibility of forward movement enabling their surfacing. They were then buried with previous collected, dried sand from the Main Ship Channel to a depth of 6.5 centimeters (approximately 2.5 inches). They were observed for the following three hours but were left undisturbed for twenty-four hours. At the same time random observations were made on the control animal's behavior.

Results

The results of the investigation are presented in Table 13. The April 19th experiment indicated a definite movement of 88 percent of the animals with 66 percent breaking the surface. The placement next to the glass wall provided an unexpected advantage. Two animals were observed rotating as their edges passed next to glass. These reactions began almost immediately and the Dendrasters had withdrawn within fifty-sixty minutes. Both animals were rotating clockwise, however, rotation counter-clockwise seems to be just as prevalent. The rotation is brought about by movement of the spines on one side, while the movements of the spines on the other side are either slowed down or stopped (Ref. 23). Another animal performing non-directional spine movements was not seen rotating, however, it withdrew from its position next to the glass within ten minutes. This could be explained by a backward or reverse movement. Chia (Ref. 23) observed reverse movements both in the field and laboratory. In all cases progress was slow and the animal either rotated or began forward movement before it had reversed more than 5 cm.



AQUARIUM LOCATION OF ORGANISMS

FIGURE 20

TABLE 13

DENDRASTER SMOTHERING EXPERIMENTS

Date	Group		Size (mm)	Health Before*	Comments	Surfaced (+) Moved (-)	Health After*	Comments
April 19	experimentals	A.	64	9		+	9	
		B.	72	9		-	6	green
		C.	69	9		+	9	
		D.	68	9		+	9	
		E.	78	7	damaged		3	greenish-yellow
		F.	70	9		+	8	
	controls		74	9			8	
			72	9			9	
			67	7	damaged		5	greenish-yellow
			65	8			8	
			63	9			9	
			70	9			9	
May 11	experimentals	A.	77	8			4	green
		B.	63	9		+	8	
		C.	71	6	damaged		0	yellow
		D.	74	9		+	8	
		E.	67	8			5	green
		F.	69	9		-	7	
	controls		73	7	damaged		2	yellowish-green
			76	5	damaged		0	yellow
			71	9			8	
			69	7	damaged		4	green
			78	9			8	
			65	8			3	green
			69	8			6	

* Numbers represent health of the animals as determined on an empirical basis. "10" indicates perfect health and "0" death.

After the 24-hour period following burial, three of the four animals which broke the surface were lying on top or next to each other. The fourth animal was separate from the group.

The experiment of May 11 was a failure caused by a combination of factors. After the 24-hour acclimation period, the animals were very slow to begin spine movement when picked up. This probably was caused by high temperature of the water in the wall tank system. The refrigerator had malfunctioned and the water was around 21°C. instead of the 11-14°C. found normally in the tanks. Damaged animals (small breaks in the test caused by the bottom grab) were showing the green color seen in the oral food tracks of some of the animals at the end of the first test. (This green color seems to indicate a slight deterioration while the yellow colored material indicated decomposition.) Additionally, the bottom material in the experimental tank was neither unsieved nor dried, thus the organic matter in it began to degrade at the elevated temperature making the substrate rancid.

Only one animal's spines were moving in what seemed to be a directed manner after burial. This animal withdrew from the glass within fifteen minutes. This was one of the two animals which surfaced.

Dendraster creeps forward along a straight line corresponding to an axis passing through the animal anteriorly-posteriorly intercepting the mouth and anus. Besides forward locomotion the animal is also capable of rotation, a feeble reversal, burrowing and righting reactions.

In the laboratory, active animals were observed moving at rates of 2-3 cm/min. They were able to bury themselves in a lateral distance of 10 cm and in less than 15 minutes time. When burying themselves, the animals seemed to pile or plow up a low mound of sand along the advancing edge. Parker and Alystyne (Ref. 26) found in Echinarachnius parma this was due to the action of the tube-feet of the anterior edge pulling the sand grains in towards the center, particularly over the anterior half of the periphery. As forward movement proceeded the animal seemed to push itself under this mound until nearly or totally covered by the sand. Once covered the animal normally would cease movement.

The mechanical forces for movement are derived from three sources. The anterior marginal spines perform digging movements which bring the anterior edge of the animal down when burrowing. The oral primary spines produce a forward motion. When the animal is placed on a piece of glass these spines can be seen launching the animal forward in a series of jerks. Each jerk moves the animal forward about 1 mm. (Ref. 23). The third mechanical force is the tube-free which are of little consequence except for their movement of sand at the anterior

edge and across the aboral surface. Although directed movements were observed shortly after the inundation, none of the animals moved to the surface during the three-hour observation period.

None of the animals assumed the oblique position at the surface observed in the field. This could be explained by the absence of a current. The advantage to the position in a moderate current would be the eddies formed. These eddies would concentrate detritus on the backside of the test or oral surface.

Dendraster's grouping in parallel rows could be a true social behavior or a simple individual response to the physical environment. This aggregative behavior is known in many echinoderms (Ref. 24) and the reasons for it are still questionable. Birkeland and Chia (Ref. 27) found Dendraster to be actively gregarious when released in subtidal enclosures. It was suggested in the same paper that these aggregations might be of some advantage to the animals as protection from the shifting sand.

Discussion

The one characteristic which typifies all species collected during the survey and the diver collections and observations with the exception of the barnacles is mobility. As previously mentioned, barnacles are not indigenous to the area. The Bar is a constantly shifting sand environment, influenced by storm-generated long-period swells, wind-generated waves, high velocity tidal currents and longshore drift. The dynamics of the overlying waters have profound impact on the shoal causing bedload movement, variable amounts of resuspension and deposition as well as deposition from external sources (i.e., the bay or coastline). This constant shifting was observed by the divers both as a turbid fluid layer which varied in depth above the compacted bottom and as sand ripples which are indicative of bed load movement. The ability of organisms to survive and proliferate in such an environment would predominantly depend on efficiency of movement on or through the substrate. Any sedentary organism requiring continuous contact with the overlying waters would soon be smothered. To avoid burial the organisms must be mobile enough to escape the deposition which normally occurs during the winter months as well as deposition and bed movements occurring during storm periods. An instantaneous deposition of 2.5 inches should not affect any of the organisms inhabiting this area. The laboratory experiment indicated that this was the case with the sand dollar (D. excentricus).

Ebert and Cordier (Ref. 21) of the California Department of Fish and Game reported and concluded much the same thing in their study of the area inside the Bar. They said (pg. 6): "Results of our sampling indicate an over-all sparse or modest biotic community. The chief limiting factor being the strong prevailing currents rendering the substrate untenable to many benthic organisms that are

necessary for a flourishing resident community. Small clams, snails and amphipods were absent in sediment samples; only a few polychaete were present. Examination of all organisms sampled indicates that they are composed of the motile, transient forms. The less motile or sedentary forms are almost non-existent .... Sediments discharged in the dumping area should have little or no effect upon the existing biotic community within the survey area."

CONCLUSIONS

Based on the studies conducted in 1971 and 1972 investigating the effects of dredging and disposal operations associated with the San Francisco Main Ship Channel project, the following conclusions can be drawn:

a. The Sediment Analysis Study demonstrated that the material being dredged is not polluted by any of the presently recognized criteria. Comparisons of the particle sizes distributions from the dredged area and the disposal area indicated the two materials are compatible and would not affect fauna habitat resulting from a substrate alteration.

b. Water quality was not degraded with respect to salinity, pH or dissolved oxygen. Turbidity levels did increase during both the dredging and the disposal operations. Although not substantiated by the transmissometer readings, the aerial photographs indicated that the plume resulting from disposal operations was ephemeral, and the plume resulting from overboarding during dredging dissipated within several minutes. The amount of turbidity caused by the operations seem insignificant when compared to the turbidity plume associated with the tidal flows through the Golden Gate.

c. The Material Dispersion Study indicated that the accumulation of dredge material when released on the southern portion of San Francisco Bar does not exceed two inches during any one release. Movement of material on the Bar takes place in two transport strata, the fluid sediment layer and the turbid suspension layer. The layers are maintained by surge and wave generated currents and moved by tidal currents. Scouring occurs around objects placed on the bar indicating that the bottom shear stresses under most conditions is capable of rapidly dispersing any short-term accumulations on the Bar. Current velocity-direction and current path studies indicate that the immediate dispersion of dredge material during settling and immediately after deposition will be primarily dependent on the tidal currents on the Bar with long-term movement directed to the south away from the channel.

d. The Benthic Community Study indicated that the organisms inhabiting the Bar were characteristic of those found in a shifting sand environment. Such an environment favors evolution of organisms capable of efficient locomotion and the ability to escape sustained burial. It is reasonable to assume that deposition of dredged material to a depth of two or three inches would make little difference to organisms able to survive mass sediment movement associated with winter storms. This assumption was not confirmed by the survey of benthic fauna before and after operations because of procedural difficulties. But it was supported by the laboratory experiment with *Dendraster excentricus*. In conclusion, it is doubtful that the dredging of the Main Ship Channel or the associated disposal operation have any long-term adverse effect on the indigenous biological community of the Bar.

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INCLOSURE 1

PREDICTED TIDAL CURRENTS AND TEST RELEASES

SAN FRANCISCO BAR DREDGE MONITORING
STATION AND TRANSECT CUBIC AUTO TAPE COORDINATES

8-10 February 1972

LOCATION	DAVIS	TENN 2
Station #1	9,560	10,500
Station #2	9,520	10,535
Station #3	9,475	10,555
Station #4	9,430	10,620
A_W	10,200	11,260
A_M	9,500	10,560
A_E	8,840	9,890
B_N	10,800	10,700
B_S	9,645	11,865
C_N	10,150	9,955
C_S	8,895	11,200
D_N	9,545	9,250
D_S	8,180	10,575
CURRENT STATION #1	9,408	10,795
CURRENT STATION #2	9,409	10,835

TIME OF PREDICTED TIDAL CURRENTS

1971

7 June (1)	8 June (2)	10 June (3)	14 June (4)	18 June (5)	25 June (6)	26 June (7)
0012s	0048s	0206s	0000s	0011e	0254s	0029f
0311e	0353e	0517e	0223f	(4.2e)	0553e	(2.4f)
(4.6e)	(4.9e)	(5.2e)	(2.1f)	0442s	(5.0e)	0342s
0742s	0818s	0936s	0524s	0717f	1018s	0635e
1023f	1059f	1217f	0829e	(3.0f)	1259f	(4.6e)
(3.5f)	(3.7f)	(3.8f)	(4.1e)	1048s	(3.8f)	1100s
1406s	1448s	1612s	1230s	1241e	1648s	1335f
1547e	1629e	1753e	1517f	(2.1e)	1854e	(3.5f)
(1.9e)	(2.0e)	(2.0)	(3.4f)	1618s	(2.2e)	1724s
1918s	1954s	2106s	1912s	1853f	2212s	1917e
2141f	2223f		2117e	(2.8f)		(2.2e)
(2.4f)	(2.5f)		(2.7e)	2212s		2300s

1. Times are corrected for the test area from the Golden Gate as follows: slack 0 minutes, maximum flood - 25 minutes, maximum ebb - 25 minutes,
2. Currents in parenthesis are maximum predicted at Golden Gate in knots.

TEST RELEASES AND SEA STATE 1971

Load Number	49	51	95	97	138	140	141
Date	10 Jun	10 Jun	14 Jun	14 Jun	18 Jun	18 Jun	18 Jun
Volume in cubic yards	2448	1700	3000	3000	2292	2010	2443
Speed of vessel in knots	5	3	3	5	3	3	3
Direction of vessel	E to W	E to W	E to W	E to W	E to W	E to W	E to W
Time at start of release	1225	1533	1234	1515	0732	1044	1226
Time at section	1227	1535	Only #4 buoy remaining		0736	1047	1230
Time at end of release	1240	1538	1242	1524	0745	1055	1238
Tidal current condition	Flood	Slack	Slack	Flood	Flood	Slack	Ebb
Time of maximum condition	1217	1612	1230	1517	0717	1048	1241
Tide at section in feet above Mean Lower Low Water	+3.4	+4.1	+0.7	+4.3	+3.4	+3.2	+2.2
Sea swells in feet	1-2	4-6	3-4	3-4	2	2	2
Wind Direction	W-NW	W-NW	NW	W-NW	calm	calm	W
Wind Speed in knots	5	20-25	10-15	10-15	0	0	5-10

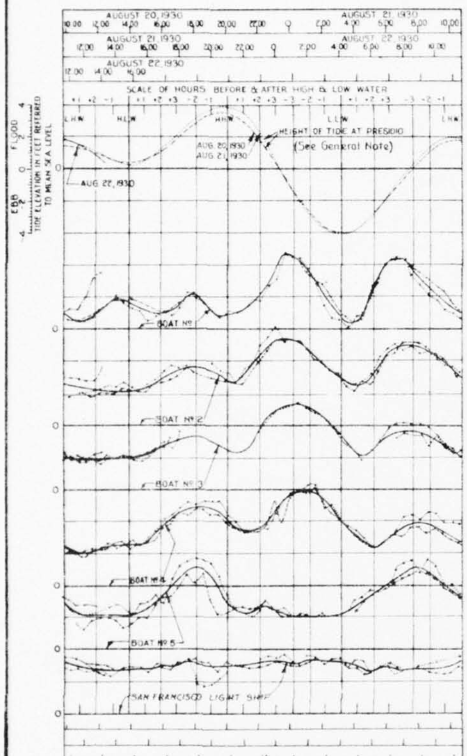

Figure 1

VELOCITY OF TIDAL CURRENT

Note: See figure 3 for cycle of velocity and direction of current.

LEGEND

First Day
Second Day
Third Day
Mean

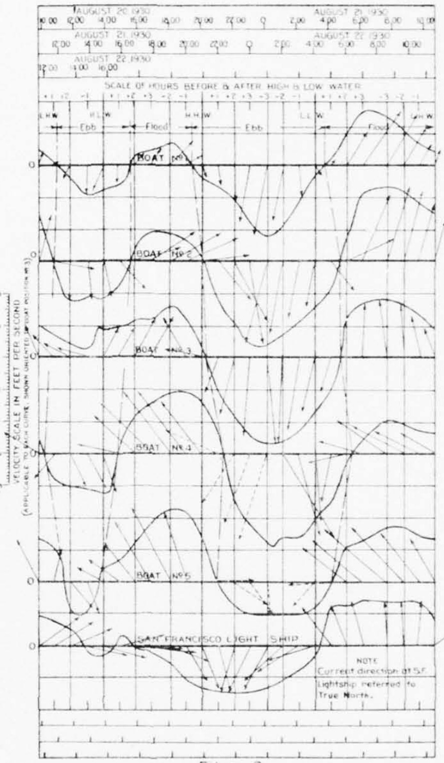

Figure 2

VELOCITY COMPONENT NORMAL TO BAR

Normal Component of Velocity
Direction of Current referred to Crest Line of Bar at Boats 1 to 5
Current direction interpolated

Note: See figures 4, 5, 6, & 7 for relation of current strength and phase to location on bar.

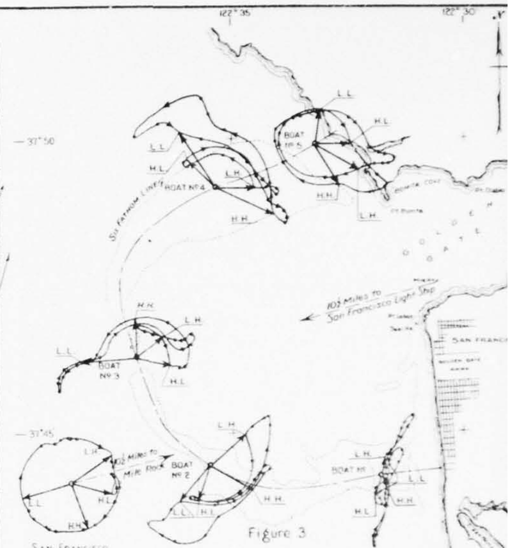

Figure 3

CURRENT DIRECTION & VELOCITY

Velocity Scale 1" = 2 Feet Per Second

Larger arrows drawn from Boat Position indicate Current Direction and Velocity to scale at times of H.H.W., L.L.W. etc. at Presidio Gage. Other arrows, shown in Figure 2, may be drawn to the center of each Curve Segment to indicate the Current Direction and Velocity at Hourly intervals before and after the High and Low Waters. Data shown are the Mean for the two days measured, see Figure 1.

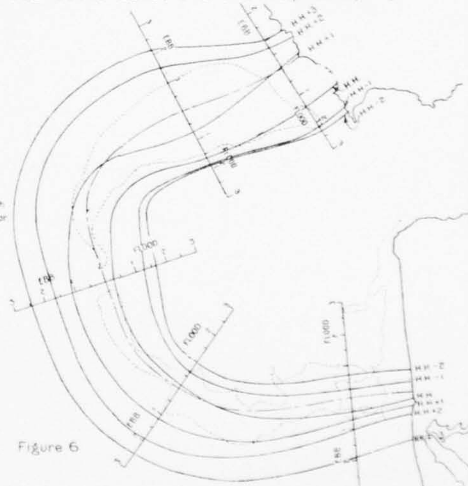

Figure 6

FLOOD DECREASING - EBB INCREASING

Two hours before H.H.W. to three hours after H.H.W.

TIDAL VELOCITY COMP

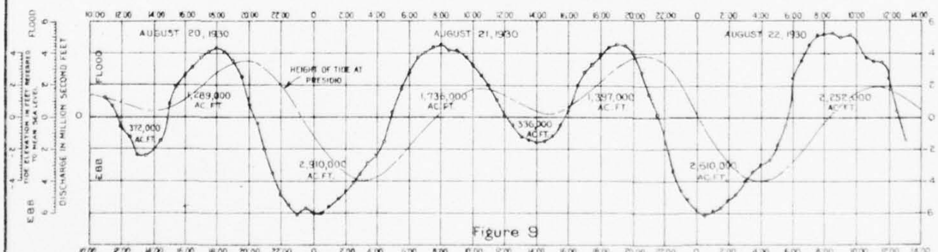

Figure 9

TIDAL FLOW ACROSS SAN FRANCISCO BAR

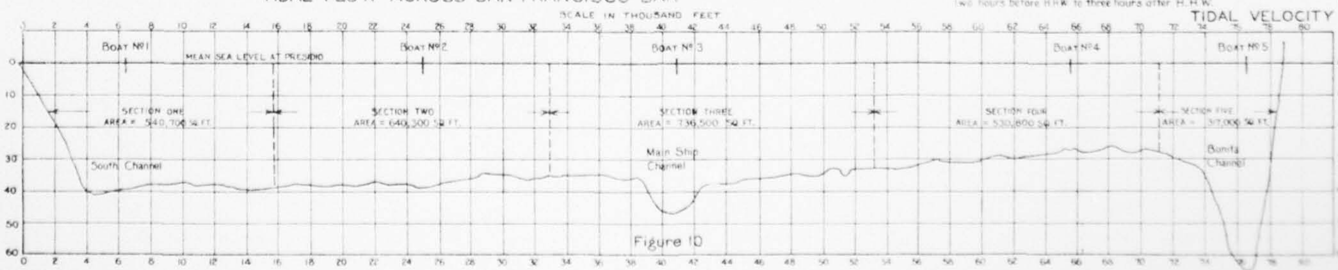

Figure 10

DEVELOPED CREST PROFILE OF SAN FRANCISCO BAR

Note: From U.S.C.&G. Survey of 1900, Main Ship Channel added from U.S.E.D. Survey, Feb. 16, 1930.

TIDE CYCLE
H.H. Aug 20 to H.H. Aug 21
H.H. Aug 21 to H.H. Aug 22
Net Volume for 2 Cycles
Average Net Volume per Cycle adjusted for Bay Storage

DIST

AD-A038 309 CORPS OF ENGINEERS SAN FRANCISCO CALIF SAN FRANCISCO--ETC F/G 13/2
DREDGE DISPOSAL STUDY, SAN FRANCISCO BAY AND ESTUARY. APPENDIX --ETC(U)
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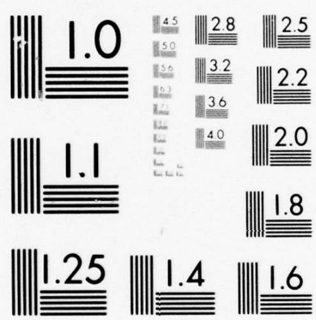


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

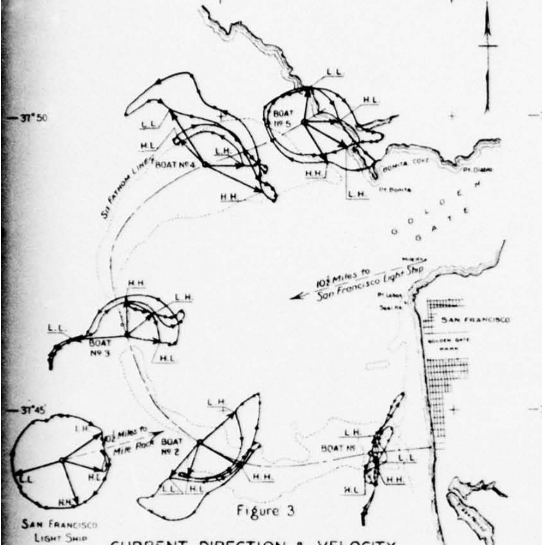


Figure 3

CURRENT DIRECTION & VELOCITY

Velocity Scale 1" = 2 Feet Per Second

Larger arrows drawn from Boat Position indicate Current Direction and Velocity to scale at times of H.H.W., L.L.W. etc at Presidio Gage. Other arrows, shown in Figure 2, may be drawn to the center of each Curve Segment to indicate the Current Direction and Velocity at Hourly intervals before and after the High and Low Waters. Data shown are the Mean for the two days measured, see Figure 1.

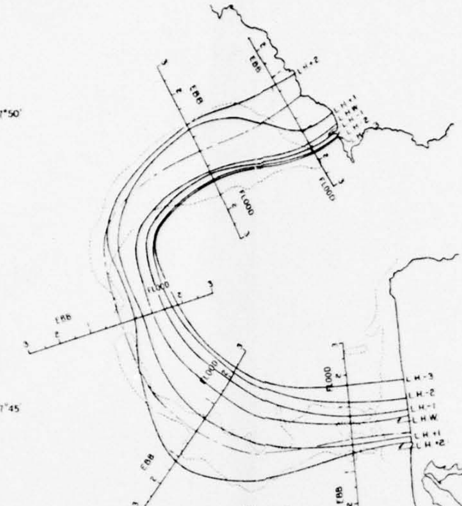


Figure 4

FLOOD DECREASING - EBB INCREASING

Three hours before L.H.W. to two hours after L.H.W.

Figure 5

EBB DECREASING - FLOOD INCREASING

One hour before H.L.W. to three hours after H.L.W.

TIDAL VELOCITY COMPONENT NORMAL TO BAR CREST

Velocity Scale 1" = 2 Feet Per Second

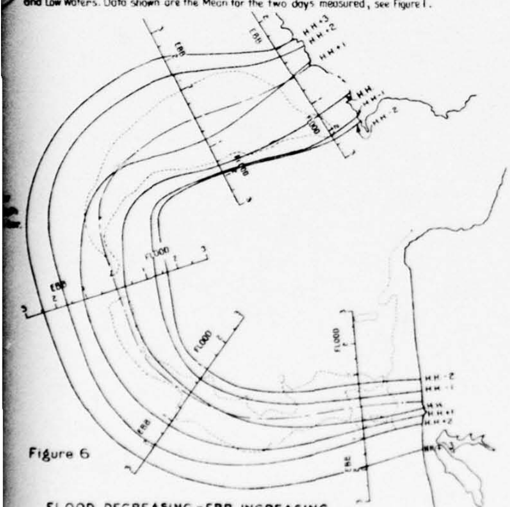


Figure 6

FLOOD DECREASING - EBB INCREASING

Two hours before H.H.W. to three hours after H.H.W.

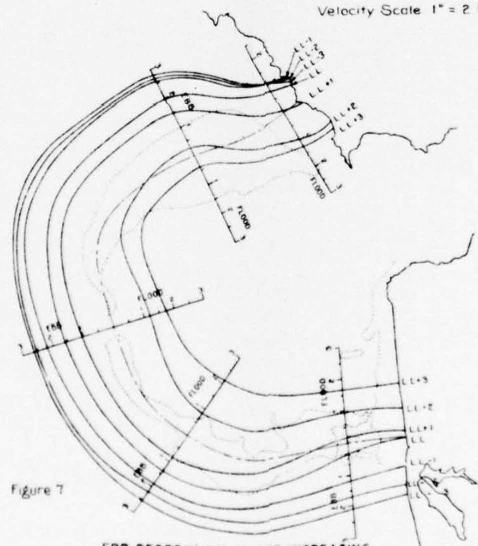


Figure 7

EBB DECREASING - FLOOD INCREASING

Three hours before L.L.W. to three hours after L.L.W.

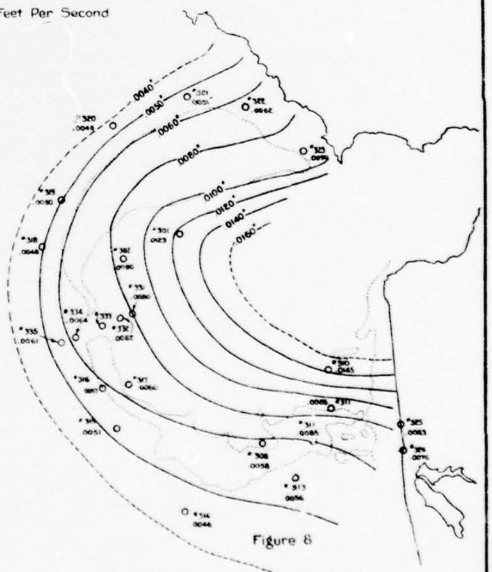


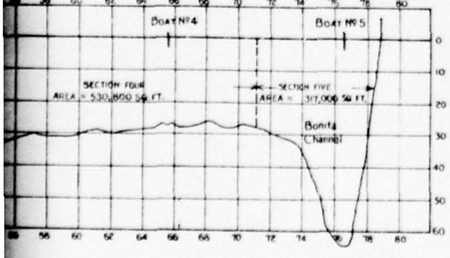
Figure 8

GRADATION OF BAR MATERIAL

Note: Contours represent mean size of sand particles. 50% by weight of each sample is retained on a sieve with a clear opening of the size noted.

TIDAL VELOCITY COMPONENT NORMAL TO BAR CREST

Velocity Scale 1" = 2 Feet Per Second



NOTE

These Tidal Measurements were made during a period of Large Tidal Range, the Diurnal Range for the two days averaging 7.8 feet as compared with a Mean Diurnal Range of 5.66 feet. At times of smaller Diurnal Range than 7.8 feet it is to be expected that Tidal Velocities will be lower and also that the relations of Time and Direction will be somewhat different than those indicated hereon.

Light Westerly Winds prevailed during these measurements.

DISTRIBUTION OF TIDAL FLOW ACROSS SAN FRANCISCO BAR

AUGUST 20—22, 1930

QUANTITY IN ACRE FEET

TIDE CYCLE	SECTION 1		SECTION 2		SECTION 3		SECTION 4		SECTION 5		NET FOR CYCLE	
	FLOOD	EBB	FLOOD	EBB	FLOOD	EBB	FLOOD	EBB	FLOOD	EBB	FLOOD	EBB
11.8 Aug 20 to 12.0 Aug 21		-132,000		-210,000	+116,000			-262,000	+231,000			-257,000
12.0 Aug 21 to 12.6 Aug 22		- 63,000		-101,000	+462,000		+23,000		+382,000		+703,000	
Net Volume for 2 Cycles		-195,000		-311,000	+578,000			-239,000	+613,000		+446,000	
Average Net Volume per Cycle adjusted for Bay Storage.		-120,000		-192,000	+223,000			-147,000	+236,000		0	

REPORT ON SACRAMENTO, SAN JOAQUIN & KERN RIVERS, CALIFORNIA

SALT WATER BARRIER INVESTIGATION

TIDAL FLOW—SAN FRANCISCO BAR

AUGUST 20, 21 & 22, 1930

U.S. Engineer Office, San Francisco, California, July 1, 1931

Transmitted with Report dated July 10, 1931

Submitted: H. G. Gwaby, Associate Engineer

Approved: R. S. Thomas, Lieut. Col., Corps of Engineers, U.S.A.

Drawn By: H.G.G. Checked By: H.G.G.

DOC. FILE	FILE	DIV.	SHEET
59lq/495	101	1	113

INCLOSURE 2

TOWILL, INC. REPORT "SAN FRANCISCO BAR DREDGE MATERIAL DISPERSION STUDY"

Towill, inc.

CIVIL ENGINEERS SURVEYORS HYDROGRAPHERS
AERIAL PHOTOGRAPHERS PHOTOGRAMMETRIC ENGINEERS

608 HOWARD STREET, SAN FRANCISCO, CALIFORNIA 94105 • TELEPHONE 415 • 982-1758

SAN FRANCISCO BAR
DREDGED MATERIALS DISPERSION STUDY

Contract No. DACW07-71-C-0063

REPORT ON CURRENT FLOW & PATH STUDIES
1971-1972

Towill, inc.

SAN FRANCISCO BAR
DREDGED MATERIALS DISPERSION STUDY

CONTRACT NO. DACW07-71-C-0063

U. S. ARMY CORPS OF ENGINEERS

Towill, inc.

TABLE OF CONTENTS

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SAN FRANCISCO BAR DREDGE
MATERIAL DISPERSION STUDY

DIVING PROGRAM

Sea state on the San Francisco Bar during the three days June 8, 10 and 18, on which diving was attempted or performed ranged from placid, long-period swells, through wind-driven chop, with waves to three to four feet, to combined swell and waves to nine feet from trough to crest. Diving was possible only when waves were less than five feet. During slack current, it may be feasible to free dive to a bottom target without a guide line, but at all times during the test period, it was found that efficient diving could be accomplished only be ascending down the buoy cables to the bottom anchor.

The diving program included the placement of graduated measuring stakes and sediment sampling plates set on the sand bottom at four locations in the test site. Placement and surveys of these devices were attempted on June 8, 1971, but extreme sea conditions forced re-scheduling of the operation. On June 10, the survey was conducted, during which time the dredge made two dumping passes through the test site at flood and slack current.

Before and after each dump, divers surveyed bottom conditions and made visual observations on the stakes to determine the sediment level, and observed the depth of sediment deposition on the sampling plates. Additional observations were made to determine evidence of scouring, type and topography of the bottom, presence of organic material and marine life, compaction of bottom sediments, and visibility and turbidity. Samples obtained included bottom surface sand and water samples, and samples of marine life. Attempts were made to obtain core samples, but the samples could not be recovered intact.

During the diving program on June 10, increasing sea state forced abandonment of the third dump and only a portion of the second post-dump survey was completed.

On June 18, 1971, a second program was conducted. The site selected was Station "F", as shown on the accompanying plan. Station "F" was located outside of the original test site so that spoil dumped in the June 10 program would not unduly influence the data obtained on June 18. The June 18 program repeated the sequence of surveys of the June 10 survey, but only one station ("F") was monitored. In addition to visual observations, underwater photographs were taken to document the sediment level observations. The accompanying Field Report Sheets and summaries describe the findings of the survey.

UNDERWATER PHOTOGRAPHY

Of the ten photographs taken on the graduated stakes during the June 18 survey, only three photographs yielded recognizable images. These photographs were taken with a 35mm. camera hand held by the divers from a distance of 2 - 3 feet.

The combined effect of reflected light from suspended material and attenuation due to turbidity resulted in generally unusable photography. It is recommended that further attempts to obtain underwater photography in the Bar area should include cameras equipped with wide angle lenses capable of focusing down to at least one foot. Diver-photographers should be equipped with sufficient weight so that photographs can be taken from a standing rather than a free-swinging position. Targets and stakes should be painted in white and orange patterns to provide contrast on color film, and the targets should be designed to ensure

positive identification of the target numerals within a limited camera field of view.

BOTTOM CONDITIONS

Throughout all stations on the Bar, bottom conditions were generally similar. Divers reported loose sand from 2-6 inches overlying compact sand at all stations on the June 10 survey; however, on the June 18 survey, no overlying loose sand was reported. Bottom samples taken on the sand surface, and by coring to two-foot depth, yielded uniformly graded sand, rich in quartz, with grain size ranging between 0.005 - 0.012 inches. Samples at all depths and locations were similar. Sand ripples, 4" x 1-1/2" deep, were noted on some dives.

No pebbles, rocks, clay, silt or organic material were noted. 3/4" diameter steel rods were driven into the compact bottom sand with 15-18 blows using a 3-pound sledge. These rods were firmly embedded to withstand current forces acting on a 3"-wide vane standing vertically 42" above the bottom, but could be broken out of the sand by firm hand pressure applied laterally at the top of the vane. A 2" diameter steel pipe, 1/8" wall thickness with 1:3 sharpened end was driven to 24 inches. Withdrawal of the pipe was effected by hand digging to the bottom of the pipe.

MARINE LIFE

A few jellyfish, 1" diameter, were noted in the zone 20 feet above the bottom and one 3" crab was noted on the bottom on June 10. Sand dollars were abundant at all stations, with density reported from 12-24 per square foot. These were found both on the sand surface and under 2-6 inches of loose sand. Some sand dollars were flat on the bottom, and many were noted on the edge, indicating

live specimens in upward or downward migration. Live sand dollar specimens, 2-3 inch diameter, were obtained and preserved in 10% formaldehyde.

VISIBILITY AND TURBIDITY

Visibility varied from less than 1 foot at the bottom to a reported 10 feet in the 0-10' depth zone. Turbidity increased with sea state and with increasing current. Local currents in the bottom 3 feet generally created turbid conditions, even during the slack current phase. Maximum visibility reported in this zone was 2 feet.

No finite measurements of turbidity were attempted. Increase in turbidity and suspended material was noted when divers made contact with the bottom, but settlement was rapid.

WATER SAMPLES

Samples were obtained at 10-ffot depth before and after dumps. 300 ml. samples for dissolved oxygen analysis were stabilized on site, by application of $MnSO_4KI$ (Azide) and H_2SO_4. Analysis of water samples for D/O and PH were made by Pacific Environmental Laboratory, using standard laboratory procedures. Water samples for the determination of turbidity were obtained after dump #3 on June 18 at a point 3 feet above the bottom.

SURVEY OF BOTTOM SEDIMENTS

Summary of survey data is shown on accompanying Figure 1.

Because of near-bottom turbidity, sediment level observations are estimated to be accurate within 1/2 inch, unless otherwise noted.

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Deposition of spoil was generally minimal except in one instance at Station "A" after dump #3 on June 10. At this station, divers performing the post-dump survey reported excessive turbidity due to the effect of six-foot waves. No observation could be made on the sediment stake, but an observation made on the spindle of the sampling plate indicated an estimated deposition of approximately 15 inches. Further surveys on this station were not possible due to increasing sea state. Because of the scouring and current action observed throughout the survey, it is apparent that the inordinate deposition of spoil at Station "A" would be transported and spread throughout the Bar area within a very short time, probably within minutes. Scouring was noted frequently. Buoy anchors, constructed of 55-gallon concrete-filled drums, were surrounded by scour depressions 6 inches deep. 12" x 12" sampling plates set dlush with the sand bottom accumulated no more than 1/2" of sediment at any time, and in most cases were void of deposition.

Dyed building sand, deposited by hand on the sampling plates, was scoured away during the depositing process.

Stakes set to measure sediment level were surrounded by scour depressions, 1-2 feet diameter, 3-4" deep. This fact was noted in the June 18 survey, and it is assumed that this condiction did exist on the June 10 survey, but was not recognized at that time because of the overcast sky with resultant lack of overhead light on June 10.

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CONCLUSION: BOTTOM SURVEY

In summary of the observations made during the diving and survey program, it is apparent that the San Francisco Bar in the test site is overlain with an homogeneous blanket of sand similar to that of the bottom samples. Depth of this blanket is unknown, but it is most probable that the samples obtained are representative of the migratory constituent of the Bar. Furthermore, the spoil dredged from the ship channel on the Bar exhibits similar physical characteristics to the native sediments on the Bar, and can be expected to react similarly under current transporting influence. Observed scouring and turbidity indicate a continuous migration of the Bar sediments, and it is improbable that dumping of spoil from the Bar channel onto the Bar could result in permanent change in elevation of the bottom surface. The potential for scour due to current action, probably exceeds, by many multiples, the deposition that would occur from sustained dumping from a dredge with similar capacity to that of the dredge "Biddle".

The effect on the only marine life noted, the sand dollars, must be determined by competent marine biologists. The foregoing comments regarding spoil deposition and bottom conditions indicate that bottom conditions are constantly in dynamic change, and spoil dumping leaves those conditions relatively unaffected. The sand dollars are capable of upward and downward migration in unconsolidated sand, and it appears that the dumping procedures observed during the test will not physically alter their normal environment nor restrain their migration.

AERIAL PHOTOGRAPHY

Photography from 3,000 feet elevaticn was obtained on June 14, 1971, using Kodak Aeroneg Color and GAF non-blue emulsion.

Exposures were made before, during and after dumping to document the surface and near-surface dispersion of sediments from the dredge "Biddle" during dumping operations.

Kodak Aerocolor Negative Film 2445

Approximate scale 1" = 500' (photos 1-15, 16, 17 1" = 750'). From review of the aerial photography, it appears that the major component of the visible plume is caused by suspended fines in the discharged water, rather than by the bulk discharge of spoil.

On photo 1-13, the plume from discharged water after dumping is visible for approximately 4,000 feet, representing a settling time of at least 15 minutes. Re-emergence of the plume is seen in the wake of a passing vessel, probably indicating incomplete settlement of the fines.

Little evidence of plume is seen in photos taken during dredging operations, and during dumping, the plume is no greater than that caused by the discharge of water.

Evidence of surface dispersion is shown in photo 1-21. In this photo, the "Biddle" is approaching the dump area, and dispersion from previous operations are seen, confined by a tidal line of demarkation.

Penetration cannot be determined in the Aeroneg photography. It is most probale that little or no penetration is seen on this photography due to the adverse optical effect created at the water surface by waves. Under conditions where

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GAF 1000 Blue Insensitive Color Film Type 2575

This film is designed to increase penetration into water by elimination of the blue sensitive emulsion; however, it is still considered experimental due to its limited commercial use. During the aerial photography program, non-blue exposures were made over the dredge "Biddle" in conjunction with the Aerocolor Negative Film 2445 exposures.

Aerial exposures obtained with this film exhibit a dense blue cast, and interpretation of imagery is impossible.

At this time, it is not known whether the film, the processing or the application is faulty; additional investigation will be conducted to determine the applicability of non-blue film to the interpretation of underwater features.

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the water surface is still, with adequate overhead lighting from the sun, we would expect that 5-10 feet of penetration could be attained in the test area.

The following summary relates the dredge operations log to the aerial photography:

PHOTO #	TIME	June 14, 1971
1-1	12:20	Dredge beginning turn to dump area, heading west.
1-2	12:20	
1-3	12:22	Continue heading to dump area.
1-4	12:22	
1-5	12:23	
1-6		Halfway into dump (4 minutes)
1-7	12:38	
1-8		
1-9		Heading east, dredging south side of channel
1-10	13:03	
1-11		
1-12		6 minutes after dump. Heading west to begin dredging.
1-13	14:04	
1-14		
1-15		Dredging south side channel, heading west.
1-16	14:08	
1-17		
1-18		Heading west, turning into dump area.
1-19	15:05	
1-20		
1-21		2 minutes into dump, heading west
1-22	15:17	
1-23		
1-24		Dredging, heading west
1-25	15:50	
1-26		
1-27		Heading west in channel, 2 minutes after end of dredging
1-28	16:30	
1-29		
1-30		Heading west, beginning turn to dump area.
1-31	16:40	
1-32		

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SAN FRANCISCO BAR DREDGED MATERIAL DISPERSION STUDY

SUMMARY OF SAMPLES OBTAINED JUNE, 1971

DESCRIPTION	STATION	DATE	TIME
1-Quart Jar - Bottom Sand - Hand Sample	A	6-10-71	12:20
1-Quart Jar - Sand dollars	B	6-10-71	11:30
1-Quart Jar - Bottom Sand	D	6-10-71	10:45
1-Pint Jar - Suspended Solids in Full Jar of Water - 3' Above Bottom	F	6-18-71	12:45
1-Quart Jar - Bottom Sand - Hand Sample	F	6-18-71	8:01
Plastic Tube Containing 1-1/2" Pipe Core Sample to 18"	F	6-18-71	10:15
Plastic Tube Containing 1-1/2" Pipe Core Sample to 20"	F	6-18-71	12:30 approx.

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CURRENT MEASUREMENTS NEAR THE
SAN FRANCISCO BAR

APPROXIMATE POSITION
LATITUDE 37°46'
LONGITUDE 122°34'

ON
7-8 JUNE 1971

M.J. DOYLE & H.J. GORMLY

Towill, inc.

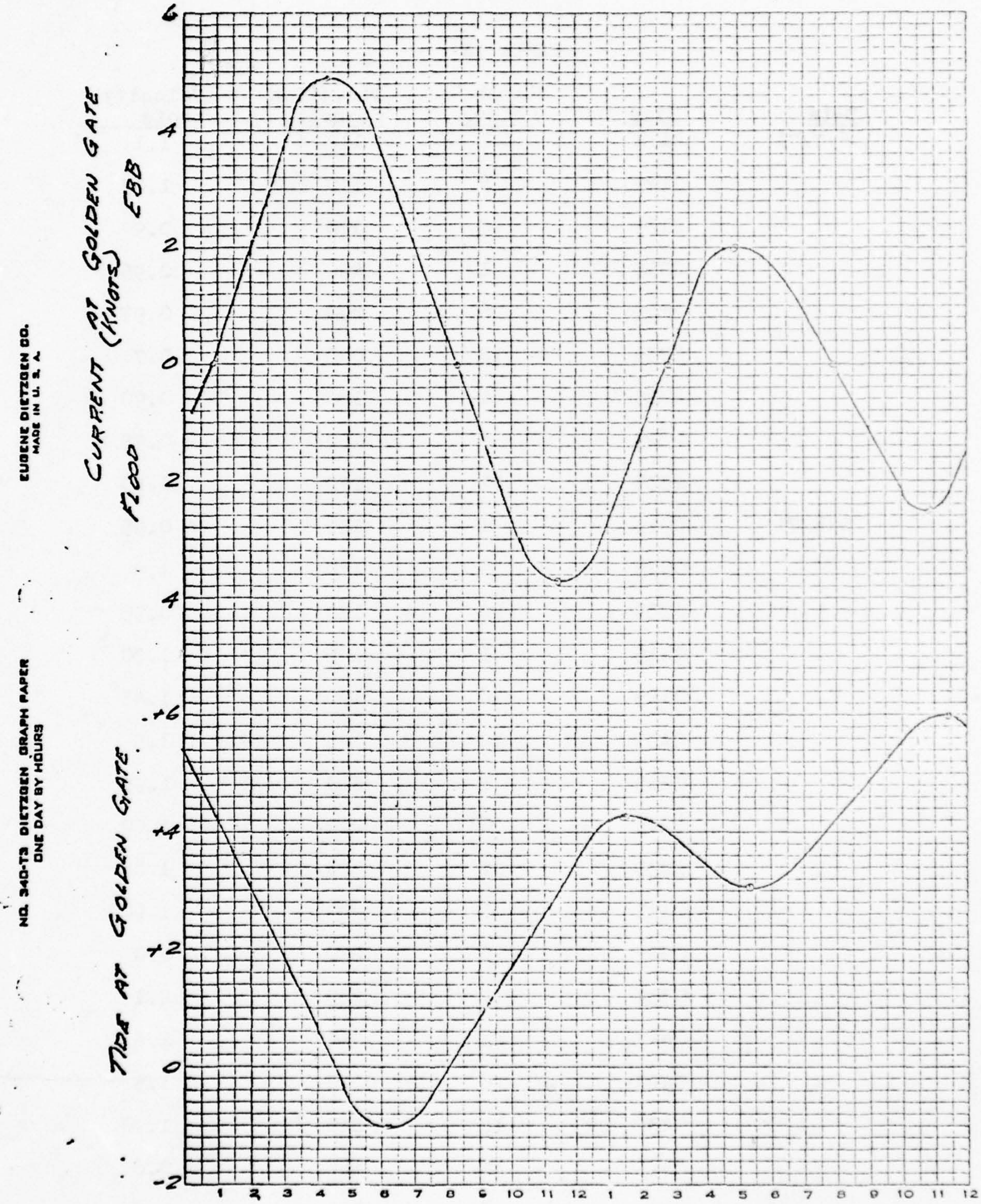
This report contains information obtained during a 24 hour current study conducted near the San Francisco Bar approximate position Lat. 37°46', Long. 122°34', on 7 - 8 June 1971. Predicted current stage at the Golden Gate is shown on Figure 1.

The information gathered during the test consists of current speed and direction measurements taken at: 1 meter below the surface, 6 meters below the surface, and 12 meters below the surface. Water depth at the current station was approximately 38 ft (MLLW). Measurements were taken using a Savonius type current velocity and direction meter (Marine Advisers, Inc, Models B-1a/B-5a and S-11).

Data obtained during this test has been reduced and is shown on Table 1. In Figure 2 the measured current velocity at three depths have been plotted as a function of time with the direction of flow indicated in degrees from magnetic north.

Figure 3 shows the extent to which the ebb current flow apparently exceeds the flood current flow. Figure 3 also shows that the measured ebb predominance is less than would be predicted from Figure 1.

Meteorological and Sea State Conditions which existed during the study are shown on Table 2.



8 JUNE 1971

FIGURE 1

(Supplied by Towill Inc.)

TABLE 1

Date	Time	Depth meters	Direction magnetic	Velocity knots
6/7/71	2115	1	110	1.1
	2125	6	110	1.05
	2135	12	110	0.9
	2215	1	090	0.95
	2225	6	090	0.97
	2235	12	090	0.7
	2315	1	130	0.90
	2325	6	150	0.75
	2335	12	170	0.60
6/8/71	0015	1	150	0.95
	0025	6	180	1.0
	0035	12	170	0.95
	0115	1	185	1.30
	0125	6	190	1.45
	0135	12	195	1.5
	0215	1	210	1.95
	0225	6	210	1.90
	0235	12	220	1.85
	0315	1	230	1.90
	0325	6	220	2.0
	0335	12	225	2.1
	0415	1	240	1.4
	0425	6	220	1.5
	0435	12	220	1.30
	0515	1	180	0.6
	0525	6	260	0.6
	0535	12	230	0.8

TABLE 1 (contd.)

Date	Time	Depth meters	Direction magnetic	Velocity knots
6/8/71	0615	1	130	0.4
	0625	6	260	1.7
	0635	12	240	1.2
	0715	1	290	0.6
	0725	6	230	1.05
	0735	12	280	1.0
	0815	1	005	0.6
	0825	6	330	0.5
	0835	12	350	0.6
	0915	1	015	0.85
	0925	6	020	0.7
	0935	12	010	0.9
	1015	1	025	1.0
	1025	6	020	1.0
	1035	12	030	1.1
	1115	1	030	1.0
	1125	6	030	1.0
	1135	12	030	1.0
	1215	1	030	0.9
	1225	6	030	1.0
	1235	12	030	1.1
	1315	1	090	0.45
	1325	6	090	0.5
	1335	12	030	0.5
	1415	1	090	0.73
	1425	6	150	0.59
	1435	12	120	0.55

TABLE 1 (contd.)

Date	Time	Depth meters	Direction magnetic	Velocity knots
6/8/71	1515	1	105	0.78
	1525	6	160	0.70
	1535	12	150	0.47
	1615	1	120	0.57
	1625	6	180	0.82
	1635	12	180	0.65
	1715	1	180	0.80
	1725	6	180	0.85
	1735	12	160	0.70
	1815	1	090	0.60
	1825	6	210	0.75
	1835	12	200	0.70
	1915	1	250	0.48
	1925	6	190	0.51
	1935	12	160	0.50
	2015	1	080	0.70
	2025	6	090	0.70
	2035	12	090	0.60

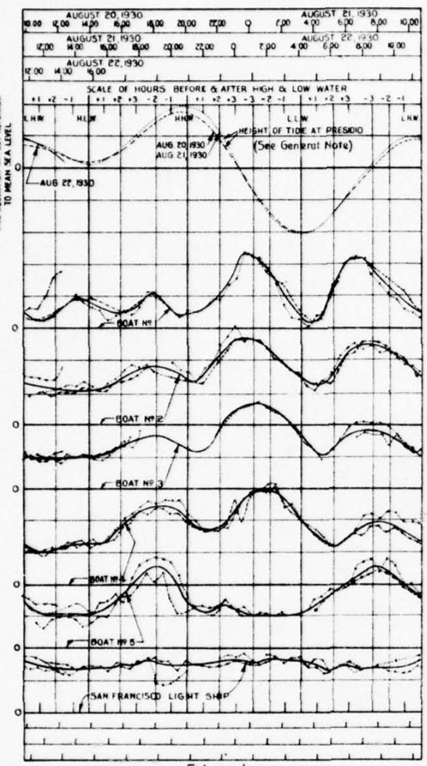


Figure 1

VELOCITY OF TIDAL CURRENT

Note: See figure 3 for cycle of velocity and direction of current.

LEGEND

First Day
Second Day
Third Day
Mean

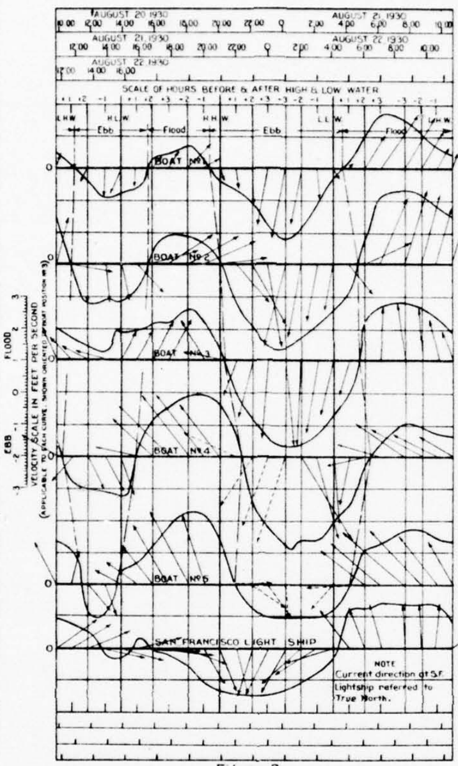


Figure 2

VELOCITY COMPONENT NORMAL TO BAR

Normal Component of Velocity
Direction of Current referred to Crest Line of Bar at Boats 1 to 5
Current direction interpolated

Note: See figures 4, 5, 6, & 7 for relation of current strength and phase to location on bar.

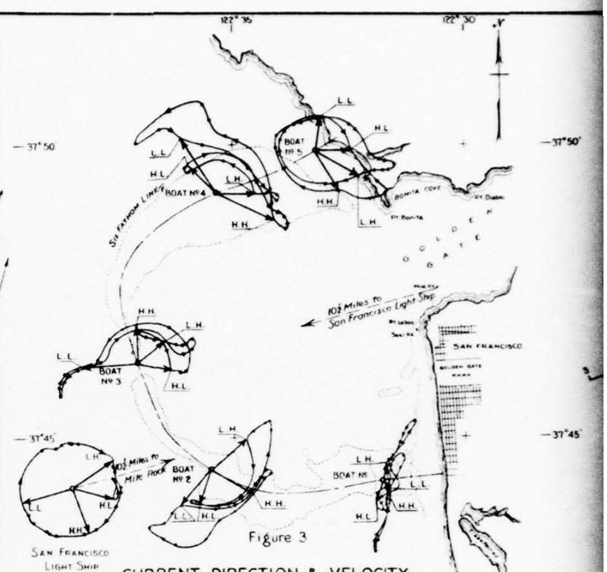


Figure 3

CURRENT DIRECTION & VELOCITY

Velocity Scale 1" = 2 Feet Per Second

Larger arrows drawn from Boat Position indicate Current Direction and Velocity to scale at times of H.H.W., L.L.W. etc. at Presidio Gage. Other arrows, shown in Figure 2, may be drawn to the center of each Curve Segment to indicate the Current Direction and Velocity at Hourly intervals before and after the High and Low Waters. Data shown are the Mean for the two days measured, see Figure 1.

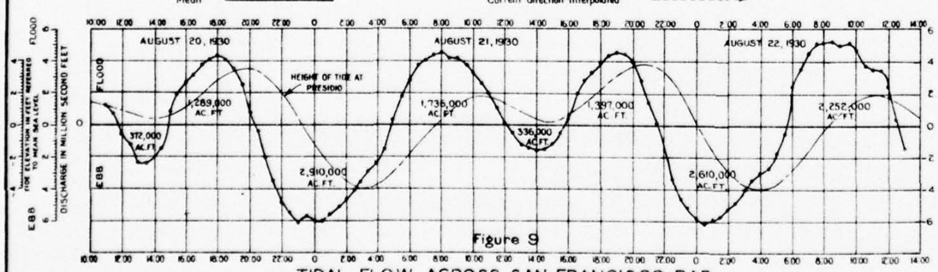


Figure 9

TIDAL FLOW ACROSS SAN FRANCISCO BAR

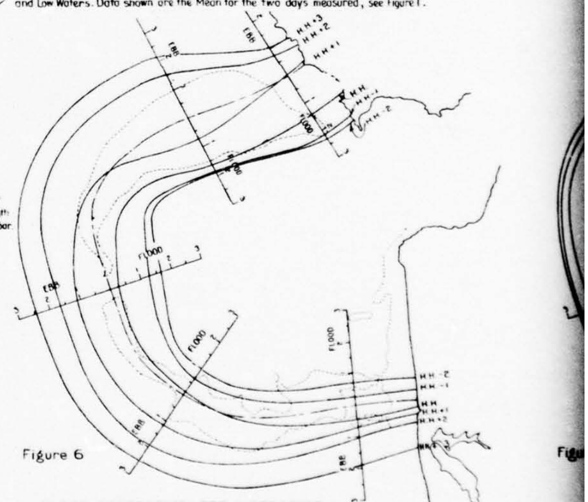


Figure 6

FLOOD DECREASING - EBB INCREASING

Two hours before H.H.W. to three hours after H.H.W.

TIDAL VELOCITY COMPONENT NO

Velocity Scale 1"

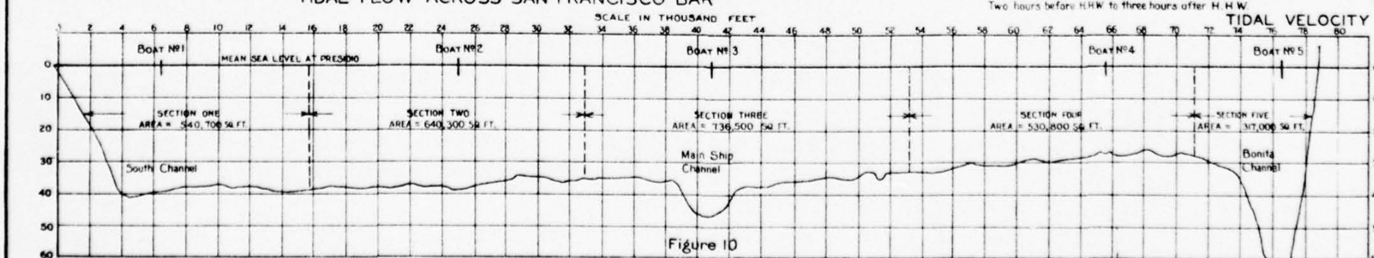


Figure 10

DEVELOPED CREST PROFILE OF SAN FRANCISCO BAR

Note: From U.S.C.&G. Survey of 1900, Main Ship Channel added from U.S.E.D. Survey, Feb. 18, 1930.

DISTRIBUTION

TIDE CYCLE	SECTION 1		SEC
	FLOOD	EBB	FLOOD
11.8 Aug 20 to 12.0 Aug 21		-132,000	
12.0 Aug 21 to 12.6 Aug 22		- 63,000	
Net Volume for 2 Cycles		-195,000	
Average Net Volume per Cycle adjusted for Bay Storage.		-120,000	

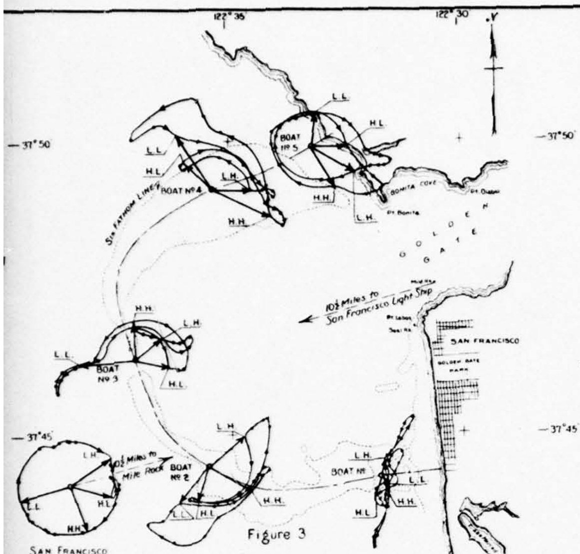


Figure 3

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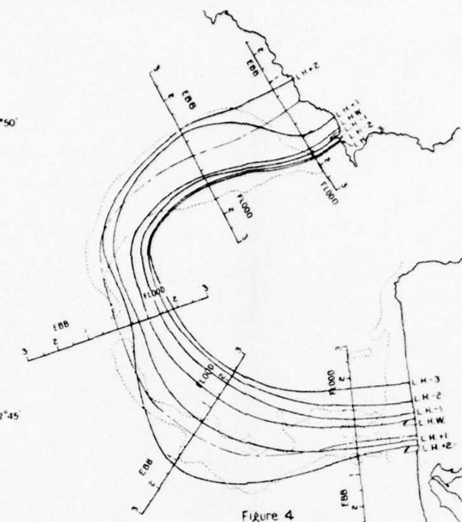


Figure 4

FLOOD DECREASING - EBB INCREASING

Three hours before L.H.W. to two hours after L.H.W.

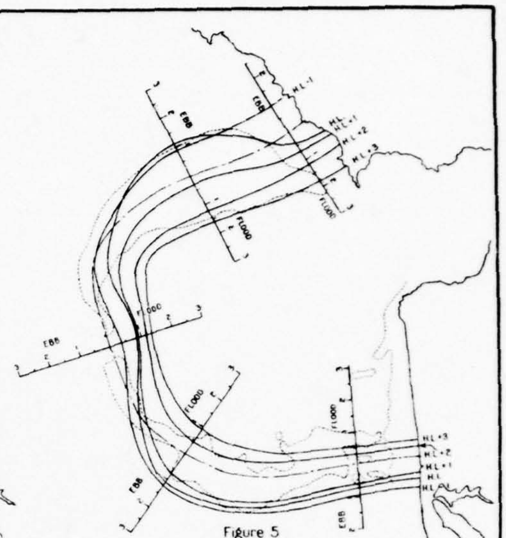


Figure 5

EBB DECREASING - FLOOD INCREASING

One hour before H.L.W. to three hours after H.L.W.

TIDAL VELOCITY COMPONENT NORMAL TO BAR CREST

Velocity Scale 1" = 2 Feet Per Second

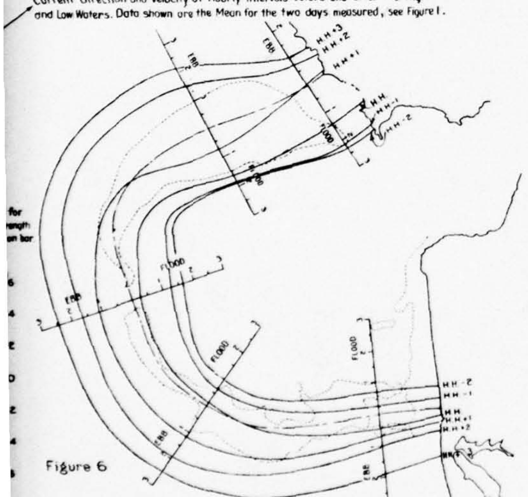


Figure 6

FLOOD DECREASING - EBB INCREASING

Two hours before H.H.W. to three hours after H.H.W.

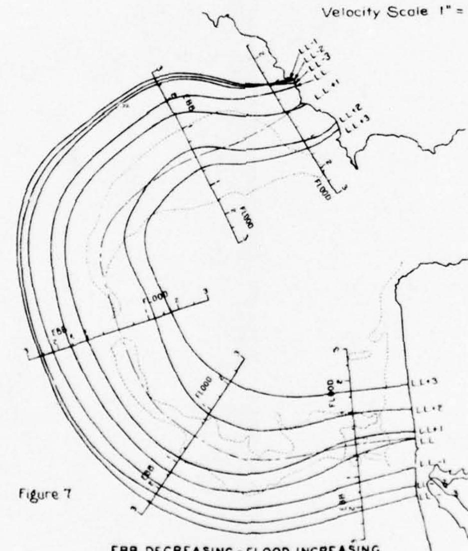


Figure 7

EBB DECREASING - FLOOD INCREASING

Three hours before L.L.W. to three hours after L.L.W.

TIDAL VELOCITY COMPONENT NORMAL TO BAR CREST

Velocity Scale 1" = 2 Feet Per Second

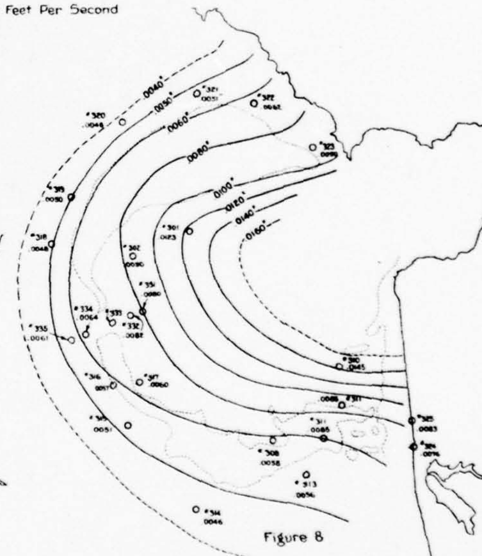
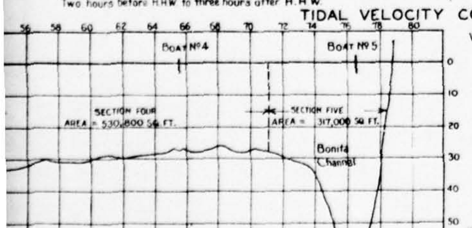


Figure 8

GRADATION OF BAR MATERIAL

Note: Contours represent mean size of sand particles. 50% by weight of each sample is retained on a sieve with a clear opening of the size noted.



NOTE

These Tidal Measurements were made during a period of Large Tidal Range, the Diurnal Range for the two days averaging 7.8 feet as compared with a Mean Diurnal Range of 5.66 feet. At times of smaller Diurnal Range than 7.8 feet it is to be expected that Tidal Velocities will be lower and also that the relations of Time and Direction will be somewhat different than those indicated hereon.

Light Westerly Winds prevailed during these measurements.

DISTRIBUTION OF TIDAL FLOW ACROSS SAN FRANCISCO BAR

AUGUST 20—22, 1930

QUANTITY IN ACRE FEET

TIDE CYCLE	SECTION 1		SECTION 2		SECTION 3		SECTION 4		SECTION 5		NET FOR CYCLE	
	FLOOD	EBB	FLOOD	EBB	FLOOD	EBB	FLOOD	EBB	FLOOD	EBB	FLOOD	EBB
11.8 Aug 20 to 12.0 Aug 21		-132,000		-210,000	+116,000			-262,000	+231,000			-257,000
12.0 Aug 21 to 12.6 Aug 22		- 63,000		-101,000	+462,000		+23,000		+382,000		+703,000	
Net Volume for 2 Cycles		-195,000		-311,000	+578,000			-239,000	+613,000		+446,000	
Average Net Volume per Cycle adjusted for Bay Storage.		-120,000		-192,000	+223,000			-147,000	+236,000		0	

REPORT ON SACRAMENTO, SAN JOAQUIN & KERN RIVERS, CALIFORNIA

SALT WATER BARRIER INVESTIGATION

TIDAL FLOW—SAN FRANCISCO BAR

AUGUST 20, 21 & 22, 1930

U.S. Engineer Office, San Francisco, California, July 1, 1931

Transmitted with Report dated July 10, 1931

Submitted: H.G. Gerdes, Associate Engineer

Approved: R.S. Thomas, Lieut. Col., Corps of Engineers, U.S.A.

Drawn By: H.G.G. Checked By: H.G.G.

DOC FILE	FILE	DIV.	SHEET
59/a/495	101	1	113

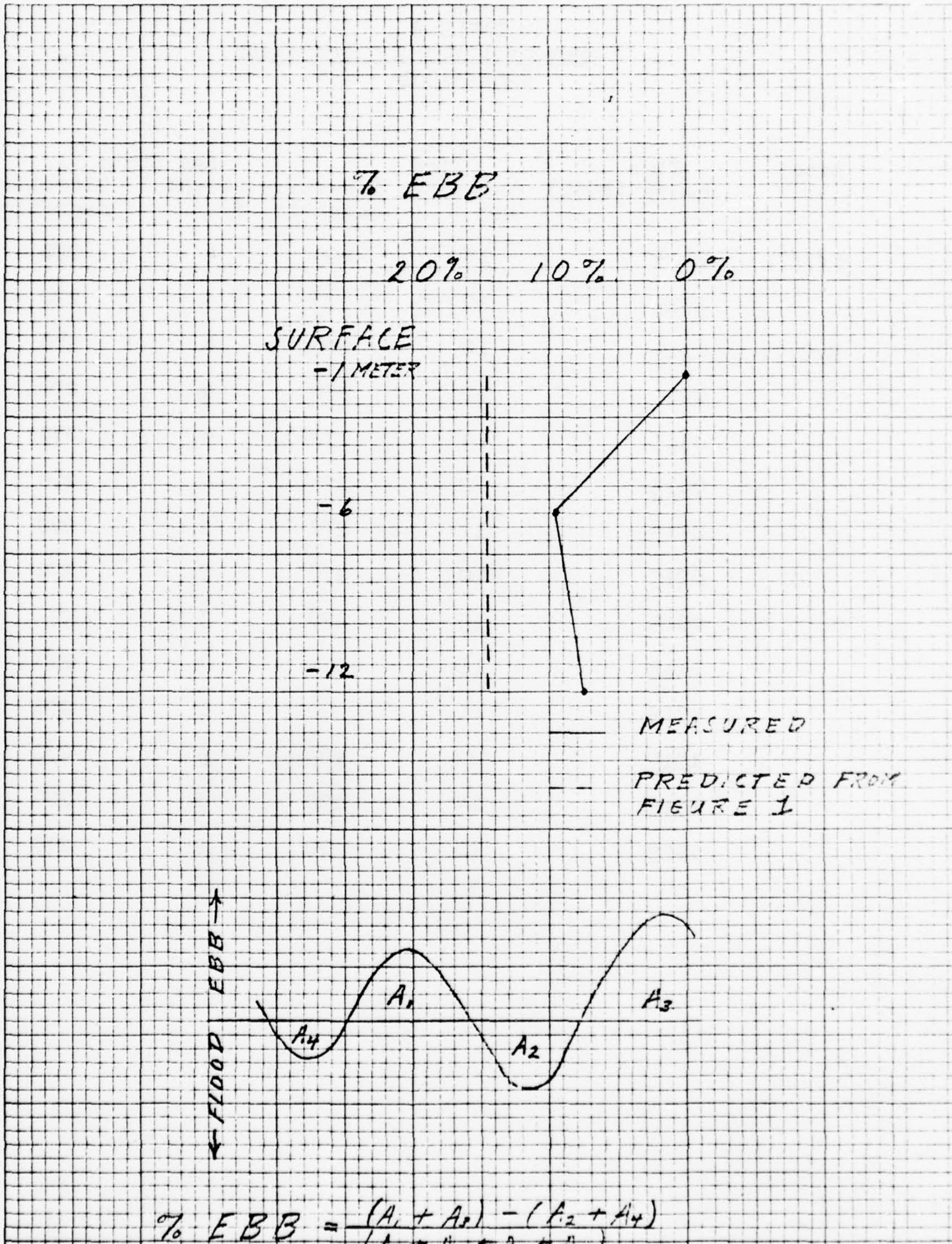

% EBB
20% 10% 0%
SURFACE
-1 METER
-6
-12
MEASURED
PREDICTED FROM FIGURE 1
← FLOOD EBB →
A_4
A_1
A_2
A_3
% EBB = $\frac{(A_1 + A_3) - (A_2 + A_4)}{(A_1 + A_2 + A_3 + A_4)}$

FIGURE 3

TABLE 2
Meteorological & Sea State Conditions

Date	Time hours (PDST)	Wind Velocity mph	Direction magnetic	Sea State Height feet	Direction magnetic
6/7/71	2115	16	260	4	270
	2315	10	270	4	270
6/8/71	0115	12	270	4	270
	0215	12	270	4	270
	0315	14	270	4	270
	0415	12	270	4	270
	0515	11	270	2	270
	0715	10	270	2	270
	0915	15	270	3	270
	1115	16	270	4	270
	1315	21	270	6	270
	1515	22	270	5	270
	1715	14	270	3	270
	1915	10	270	2	270

TEMPERATURE, SALINITY AND DENSITY DATA
OBTAINED FROM SAMPLES TAKEN ON
8 JUNE 1971
at
LAT. 37°46', LONG. 122°34' (Approx.)

TIME, HOURS	DEPTH, FEET	SALINITY, o/oo	TEMPERATURE, °C	DENSITY
0600	Surf.	33.49	10.2	25.76
0600	18	33.51	9.7	25.87
0600	36	33.80	9,5	26.12
1300	Surf.	33.49	10.5	25.71
1300	18	33.56	10.1	25.85
1300	36	33.77	9.7	26.18
1700	Surf.	33.58	10.6	25.77
1700	18	33.46	10.6	25.66
1700	36	33.64	10.2	25.88
2300	Surf.	33.63	9.9	25.93
2300	18	33.81	9.4	26.15
2300	36	33.84	9.4	26.16

A Bathermograph was used for temperature/depth profiles. Water samples were obtained by Frautschy bottles. Surface water temperatures were measured with a laboratory standard thermometer. Salinity was determined by an Induction Salinometer. Densities were computed using Knudsens Table s.

Towill, inc.

CURRENT MEASUREMENTS NEAR THE
SAN FRANCISCO BAR

APPROXIMATE POSITION
LATITUDE 37°46'
LONGITUDE 122°34'

ON

25-26 JUNE 1971

M.J.Doyle & H.J.Gormly

This report contains information obtained during a 25 hour current study conducted near the San Francisco Bar on 25-26 June 1971.

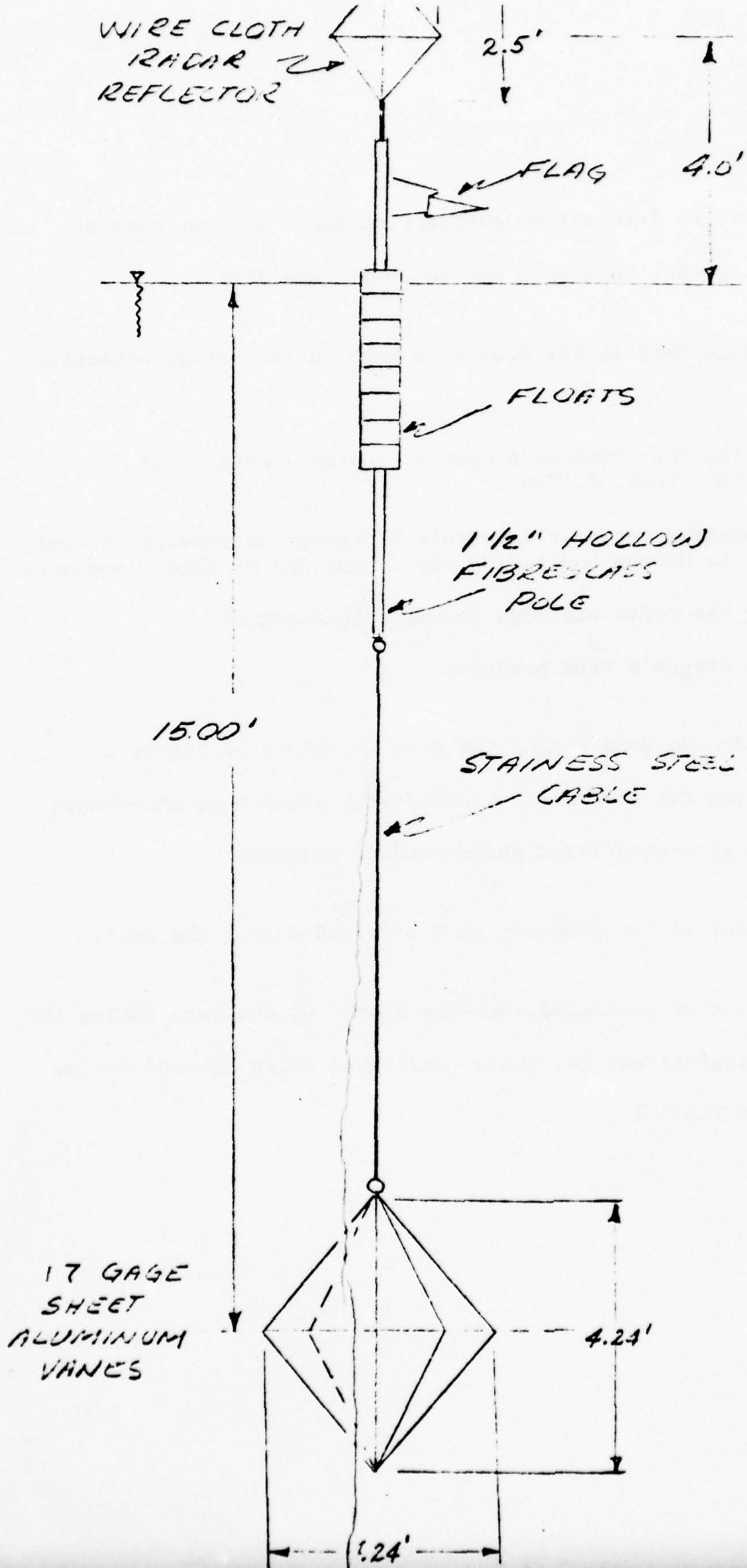
The test procedure used in the drogue or path current study consisted of:

1. Releasing the free running drogue at a preselected point (Lat. 37° 46', Long. 122°34')
2. At approximately one hour intervals bringing the research vessel alongside the drogue and taking radar bearings on fixed landmarks
3. Correcting the radar bearings to magnetic bearings
4. Fixing the drogue's true position

Details of the drogue used during the test are shown in Figure 1. Bearings recorded during the test were obtained with a Raytheon ship-board radar, and a Raytheon gyro-stabilized ships heading compass.

Figure 2 is a plot of the drogue's path observed during the test.

Figure 3 is a plot of predicted currents at the Golden Gate during the test period. Meteorological and Sea State Conditions which existed during the study are shown on Table 1.



CURRENT
DROGUE

FIGURE

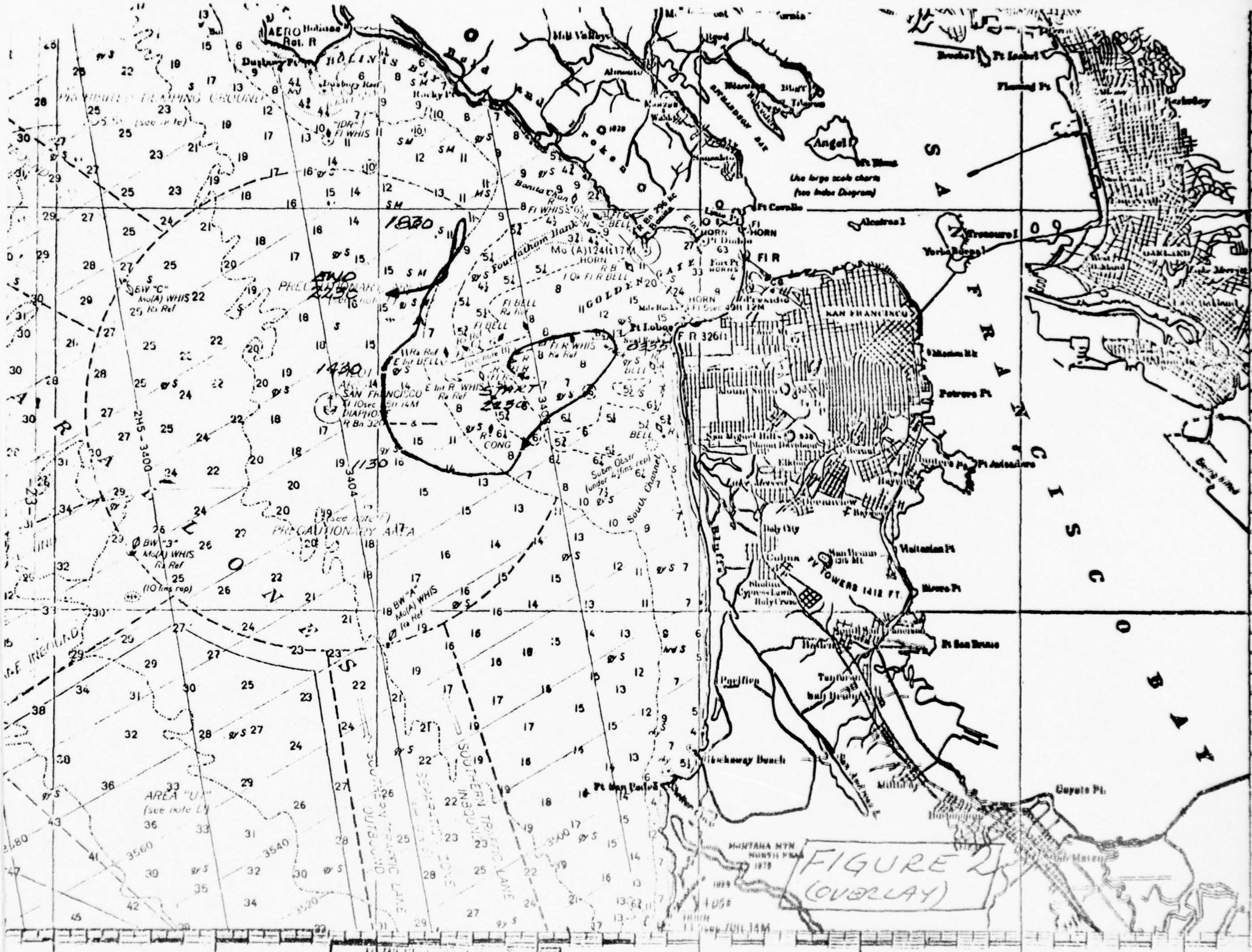
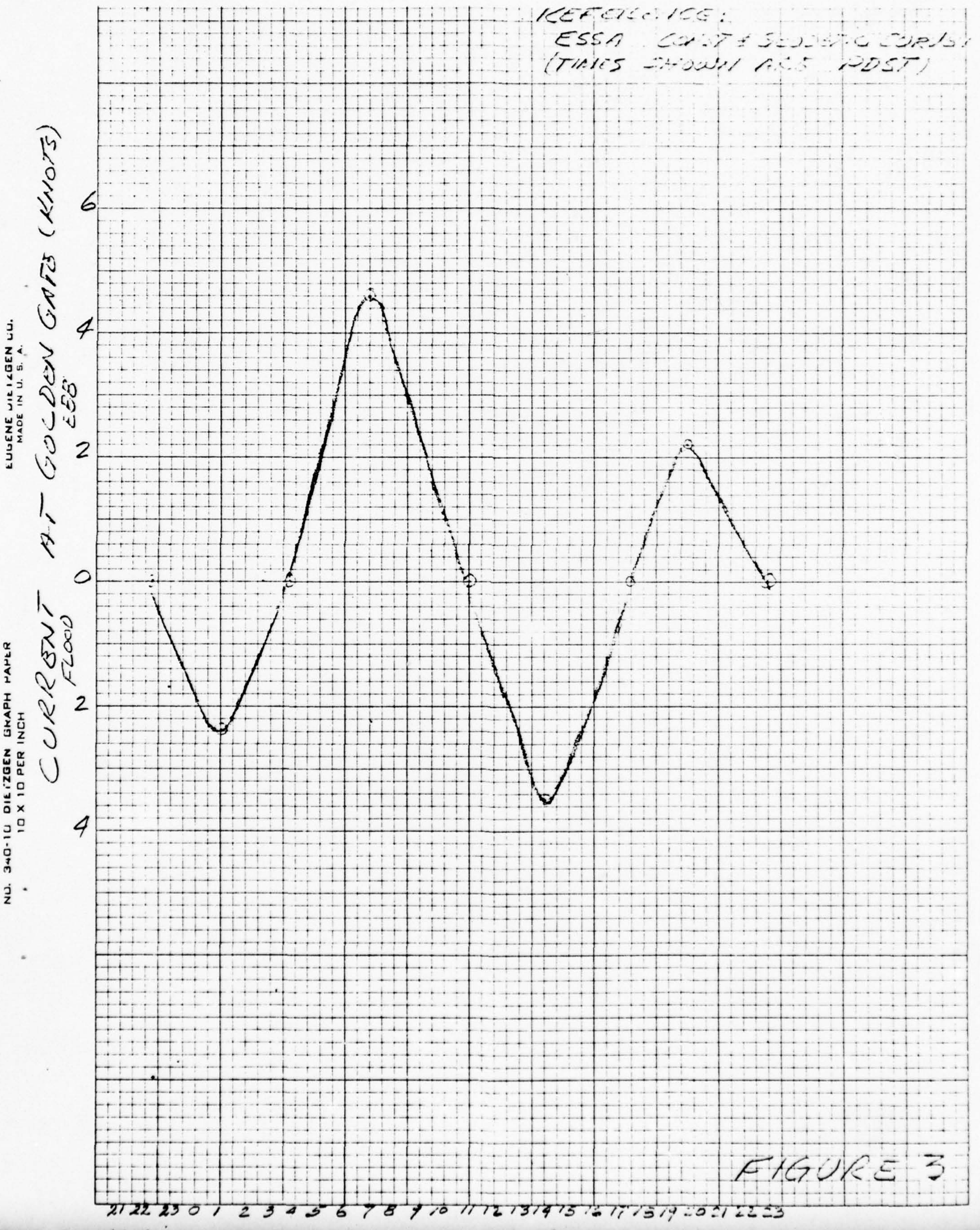


FIGURE 2 (OVERLAY)



REFERENCE:
ESSA COAST & GEODETIC SURVEY
(TIMES SHOWN ARE PDST)
CURRENT AT GOLDEN GATE (KNOTS)
EBB
FLOOD
6
4
2
0
2
4
21 22 23 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
25 JUNE
26 JUNE
NO. 340-10 DIETZGEN GRAPH PAPER
10 X 10 PER INCH
EUGENE DIETZGEN CO.
MADE IN U. S. A.

FIGURE 3

TABLE NO. 1

METEOROLOGICAL AND SEA STATE CONDITIONS

DATE	TIME HOURS (PDST)	WIND VELOCITY MPH	WIND DIRECTION MAGNETIC	SEA STATE HEIGHT FEET	SEA STATE DIRECTION MAGNETIC
6/25/71	2230	3	170	1	230
	2330	3	230	1	230
6/26/71	0030	3	230	1	230
	0215	3	230	1	230
	0255	3	230	1	230
	0335	3	230	1	230
	0430	2	230	1	230
	0530	2	230	1	230
	0630	2	230	1	230
	0730	5	240	1	230
	0830	5	240	1	230
	0930	4	240	1	230
	1030	4	220	1	230
	1130	CALM		1	230
	1230	CALM		1	230
	1330	CALM		1	230
	1430	CALM		1	230
	1530	2	270	1	270
	1630	CALM		1	270
	1730	CALM		1	270
	1830	6	270	1	270
	1930	8	270	2	270
	2030	8	270	2	270
	2130	7	270	2	270
	2230	7	270	2	270

PACIFIC ENVIRONMENTAL LABORATORY
657 Howard Street, San Francisco 94105
Phone - (415) 362-6065

Received 6/21/71

Reported 6/22/71

WASTEWATER ANALYSIS REPORT

R TOWILL, INC. REPORT TO W. S. ROBINSON

ADDRESS 608 HOWARD STREET, SAN FRANCISCO, CALIFORNIA 94105

B NO.	71925	71926	71927	71928
SOURCE OF SAMPLE: SAN FRANCISCO BAR	F 10' Depth 27 min.after Dump #1	F Buoy 3E Reset 10' depth	F Buoy 3E 10' Depth	F 3' above botto @ 45' Depth
TREATMENT:		Predump #2	Post dump #2	
DATE COLLECTED:	6/18/71	6/18/71	6/18/71	6/18/71
TIME COLLECTED:	0801	1015	1130	1240

Analysis	Units	ANALYTICAL RESULTS			
DISSOLVED OXYGEN	Mg/L	8.7	6.3	6.5	8.8
pH	Unit	7.7	7.7	--	7.7 --

COMMENTS:

Samples were pretreated in the field with $MnSO_4$, KI-Azide and H_2SO_4 and submitted to laboratory for analyses of dissolved oxygen concentration.

Analysis by: "Standard Methods for the Examination of Water and Wastewater", Current Edition, APHA

TN Analyst

R A Ryder Director
R. A. Ryder

Ammended by addition of record date 7-6-71 [illegible]

PACIFIC ENVIRONMENTAL LABORATORY
657 Howard Street, San Francisco 94105
Phone - (415) 362-6065

Received 6/21/71

Reported 6/22/71

WASTEWATER ANALYSIS REPORT

R	TOWILL, INC.	REPORT TO	W. S. ROBINSON		
ADDRESS	608 HOWARD STREET, SAN FRANCISCO, CALIFORNIA 94105				
B NO.		71924			
S^URCE OF SAMPLE:	SAN FRANCISCO BAR	A			
		10' depth			
EATMENT:					
DATE COLLECTED:		6/10/71			
ME COLLECTED:		12:40			

alysis	Units	ANALYTICAL RESULTS			
DISSOLVED OXYGEN	Mg/L	7.2			

COMMENTS:

This sample was pretreated in the field with $MnSO_4$, KI-Azide and H_2SO_4 and submitted to laboratory for analyses of dissolved oxygen concentration.

Analysis by: "Standard Methods for the Examination of Water and Wastewater", Current Edition, APHA

TN Analyst

R. A. Ryder Director
R. A. Ryder

7-6-71 R.A.R.
Ammended by addition of record data.

PACIFIC ENVIRONMENTAL LABORATORY
657 Howard Street, San Francisco 94105
Phone - (415) 362-6065

Received 6/21/71

Reported 6/22/71

WASTEWATER ANALYSIS REPORT

FOR TOWILL, INC. REPORT TO W. S. ROBINSON

ADDRESS 608 HOWARD STREET, SAN FRANCISCO, CALIFORNIA 94105

LAB NO. 71924

SOURCE OF SAMPLE: SAN FRANCISCO BAR A

TREATMENT:

DATE COLLECTED: 6/10/71

TIME COLLECTED: --

Analysis	Units	ANALYTICAL RESULTS			
DISSOLVED OXYGEN	Mg/L	7.2			

COMMENTS:

This sample was pretreated in the field with $MnSO_4$, KI-Azide and H_2SO_4 and submitted to laboratory for analyses of dissolved oxygen concentration.

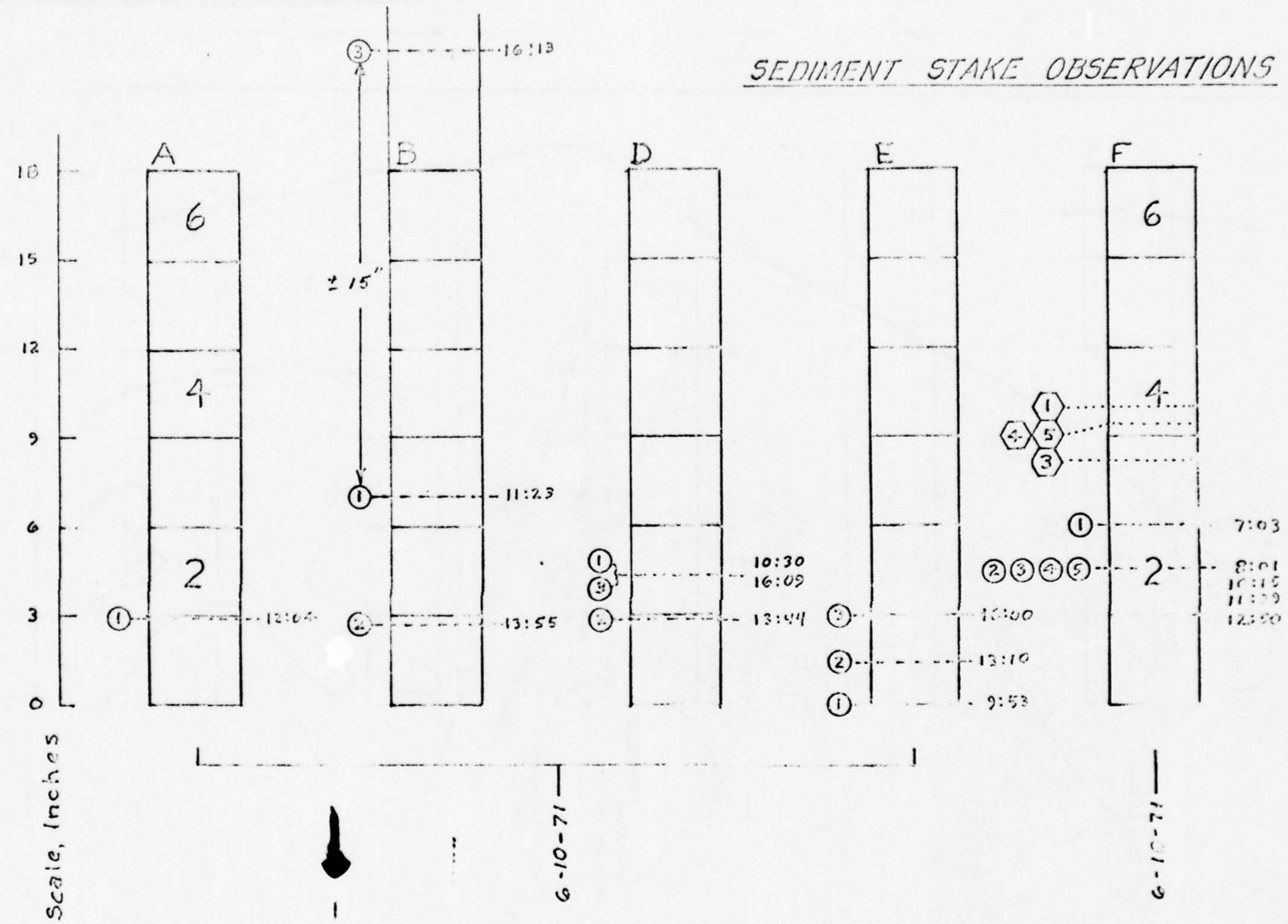
Analysis by: "Standard Methods for the Examination of Water and Wastewater", Current Edition, APHA

TN Analyst

R. A. Ryder Director

R. A. Ryder

SEDIMENT STAKE OBSERVATIONS



6-10-71	Dump #1	12:15
	Dump #2	15:35
6-18-71	Dump #1	7:33
	Dump #2	10:46
	Dump #3	12:29

FIG. # 1.

○ Bottom of scour depression
⬡ Top " " "

605 HOWARD STREET
SAN FRANCISCO, CA. 94105

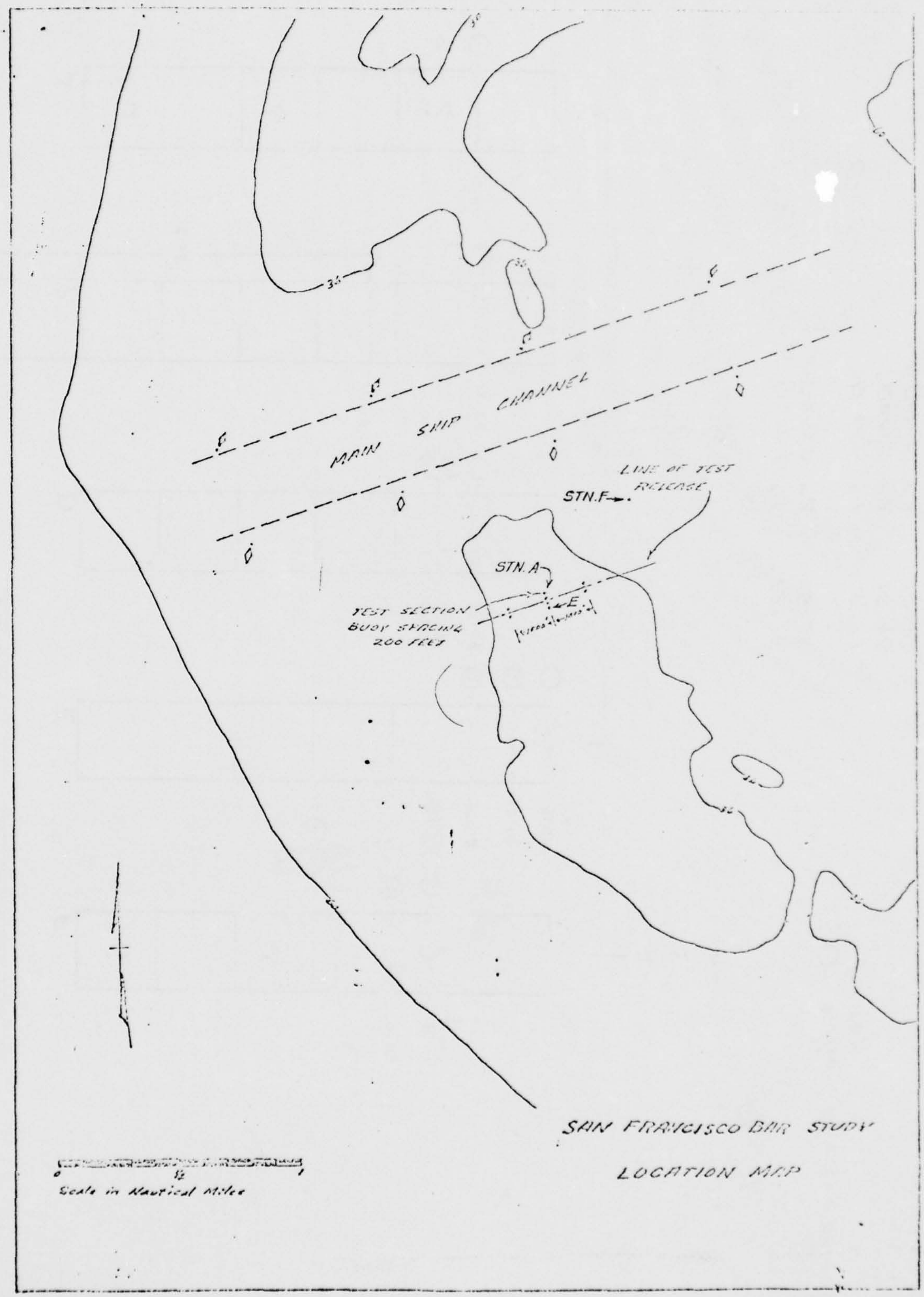

MAIN SHIP CHANNEL
LINE OF TEST RELEASE
STN. F
STN. A
E
TEST SECTION
BUOY SPACING
200 FEET
0
1/2
1
Scale in Nautical Miles
SAN FRANCISCO BAR STUDY
LOCATION MAP

PLATE 2

A1

FIELD REPORT
SAN FRANCISCO BAR DREDGE SPOIL DISPERSION STUDY

Towill, inc.

Station No. or Location A Buoy 3A

Divers In, Time 12:04 Out, Time 12:20 Date 6-10-71

Diver 2 Recorded By WSR

Stake Reading ______ Fathometer Depth ______

Color of Sand Deposited ______ Visibility, feet 1'

Turbidity, materials in suspension ______

Catenary and Scope of Buoy Anchor Lines 45° Taut.

BOTTOM CONDITIONS

1. Marine life, what kind Sand dollars 1 doz/sq ft.
   Moving or sessile standing vertically on sand surface
   In water or on bottom ______
2. Organic materials (any layer of organic material, sterile bottom or scour) ______
3. Type of sediment (clay, silt, sand or rocks) 8" loose sand on hard
4. Compaction of sediment (penetration easy or difficult) ______
5. Topography (smooth, ripple marks, pebbles, rock size) fine sand 4" ripples 1" deep.

Samples Obtained: Type Bag sand.

Tag Numbers 4, ______, ______

How many photos on stake 0

How many photos this dive 0 Photo Numbers ___,___,___

Comments B stake was set in A position.

Other tasks performed Set stake, sample disk not set

Marker buoy fouled survey vessel. Stn A lost.
(Added note 6-28-71 WAR)

B 1

FIELD REPORT
SAN FRANCISCO BAR DREDGE SPOIL DISPERSION STUDY

Towill, inc.

Station No. or Location B #3

Divers In, Time ~~11:10~~ 11:27 Out, Time ~~11:13~~ 11:35 Date 6-10-71

Diver 2 Recorded By WSR

Stake Reading 3.0 Fathometer Depth

Color of Sand Deposited None. Visibility, feet 2 ft.

Turbidity, materials in suspension bottom 10' med turbid
visibility on surface 10' ± 5-10'

Catenary and Scope of Buoy Anchor Lines 45° + 150 ft

BOTTOM CONDITIONS

1. Marine life, what kind Sand dollars
   Moving or sessile sessile.
   In water or on bottom bottom
2. Organic materials (any layer of organic material, sterile bottom or scour) sterile
3. Type of sediment (clay, silt, sand or rocks) 2' loose sand Hard under.
4. Compaction of sediment (penetration easy or difficult) 18" penetration stands firm. medium
5. Topography (smooth, ripple marks, pebbles, rock size)

Samples Obtained: Type ~~No sampler~~ Sand dollars.

Tag Numbers 3, ,

How many photos on stake 0

How many photos this dive 0 Photo Numbers , ,

Comments 1st dive aborted - current too strong to swim to buoy.

Other tasks performed Set stake only. plate not set.

14
12
10
8
6
4
2

FIELD REPORT
SAN FRANCISCO BAR DREDGE SPOIL DISPERSION STUDY

B2

Towill, inc.

Station No. or Location B Buoy # 3

Divers In, Time 13:55 Out, Time 14 Date 6-10-71

Diver McPhetres Recorded By WOR

Stake Reading .9 Fathometer Depth

Color of Sand Deposited ~~Brown~~ Red none Visibility, feet 2 ft

Turbidity, materials in suspension —

Catenary and Scope of Buoy Anchor Lines

BOTTOM CONDITIONS

1. Marine life, what kind Many Sand dollars, no crabs.
   Moving or sessile
   In water or on bottom surface & buried s/d
2. Organic materials (any layer of organic material, sterile bottom or scour) None - sterile sand
3. Type of sediment (clay, silt, sand or rocks) Sand, no scour noted.
4. Compaction of sediment (penetration easy or difficult)
5. Topography (smooth, ripple marks, pebbles, rock size)

Samples Obtained: Type

Tag Numbers ____, ____, ____

How many photos on stake

How many photos this dive Photo Numbers ___, ___, ___

Comments

Other tasks performed Set plate. (not set during prev. dive.

14
12
10
8
6
4
2

9

B3

FIELD REPORT
SAN FRANCISCO BAR DREDGE SPOIL DISPERSION STUDY

Towill, inc.

Station No. or Location B buoy #3

Divers In, Time 14:36 Out, Time 14:42 Date 6-10-71

Diver 1 Recorded By WSR

Stake Reading ________ Fathometer Depth 36'

Color of Sand Deposited ________ Visibility, feet ________

Turbidity, materials in suspension ________

Catenary and Scope of Buoy Anchor Lines ________

BOTTOM CONDITIONS

1. Marine life, what kind ________

   Moving or sessile ________

   In water or on bottom ________

2. Organic materials (any layer of organic material, sterile bottom or scour) ________

3. Type of sediment (clay, silt, sand or rocks) ________

4. Compaction of sediment (penetration easy or difficult) ________

5. Topography (smooth, ripple marks, pebbles, rock size) ________

Samples Obtained: Type ________

Tag Numbers ________, ________, ________

How many photos on stake ________

How many photos this dive ________ Photo Numbers ___, ___, ___

Comments ________

Other tasks performed Attempted to obtain 2" core sample. Drove to 18" - not successful in retrieving core - Too fluid ~~[illegible]~~

14
12
10
8
6
4
2

B4

(6)

FIELD REPORT
SAN FRANCISCO BAR DREDGE SPOIL DISPERSION STUDY

Towill, inc.

Station No. or Location B buoy 3

Divers In, Time 16:18 Out, Time 16:25 Date 6-10-71

Diver Johnson Recorded By GWR

Stake Reading Could not find Fathometer Depth

Color of Sand Deposited — Visibility, feet ~1'

Turbidity, materials in suspension

Turbid - felt sand in water.

Catenary and Scope of Buoy Anchor Lines

BOTTOM CONDITIONS

1. Marine life, what kind Few sand dollars seen.

   Moving or sessile

   In water or on bottom Some on edge some

2. Organic materials (any layer of organic material, sterile bottom or scour)

3. Type of sediment (clay, silt, sand or rocks)

4. Compaction of sediment (penetration easy or difficult)

5. Topography (smooth, ripple marks, pebbles, rock size)

Samples Obtained: Type

Tag Numbers , ,

How many photos on stake

How many photos this dive Photo Numbers , ,

Comments Sea swell plus waves ± 4-6'

Wind 15 mph. SW.

Other tasks performed Attempted metal tube core sample.

Drove 24" Constant drive

Felt like ~~consolidated~~ compacted sand

Sediment half way up disk spindle (± 15")

14
12
10
8
6
4
2

FIELD REPORT
SAN FRANCISCO BAR DREDGE SPOIL DISPERSION STUDY

B5

Towill, inc.

Station No. or Location B Buoy 3

Divers In, Time 16:40 Out, Time 16 55 Date 6-10-71

Diver 1 Kennedy Recorded By WDR

Stake Reading Could not find. Fathometer Depth

Color of Sand Deposited Could not find disk Visibility, feet 1-2'

Turbidity, materials in suspension very Turbid due to sea state.

Catenary and Scope of Buoy Anchor Lines 0-45° slack-taut

BOTTOM CONDITIONS

1. Marine life, what kind sparse sand dollars

   Moving or sessile

   In water or on bottom

2. Organic materials (any layer of organic material, sterile bottom or scour)

3. Type of sediment (clay, silt, sand or rocks) Sand.

4. Compaction of sediment (penetration easy or difficult)

5. Topography (smooth, ripple marks, pebbles, rock size)

   local scour around anchor - not too visible

Samples Obtained: Type

Tag Numbers ______, ______, ______

How many photos on stake

How many photos this dive ______ Photo Numbers ___, ___, ___

Comments Bottom felt same as before.

Other tasks performed Recover sampling disk. Very dark - Turbid. Could not locate either stake or plate.

14
12
10
8
6
4
2

D1

FIELD REPORT
SAN FRANCISCO BAR DREDGE SPOIL DISPERSION STUDY

Towill, inc.

Station No. or Location D Buoy #4

Divers In, Time 10:30 Out, Time 10:42 Date 6-10-71

Diver 4 Recorded By WDR

Stake Reading ______ Fathometer Depth 35'

Color of Sand Deposited — Visibility, feet 1-2'

Turbidity, materials in suspension dark & Turbid

Catenary and Scope of Buoy Anchor Lines 45° - strained vibrating

BOTTOM CONDITIONS

1. Marine life, what kind Sand dollars on edge No organic

   Moving or sessile ______

   In water or on bottom 6" under sand

2. Organic materials (any layer of organic material, sterile bottom or scour) 125 sand dollars/sq ft Fiddler crabs 3½" grass

3. Type of sediment (clay, silt, sand or rocks) fine dark sand

4. Compaction of sediment (penetration easy or difficult) 15 sledge blows/18"

5. Topography (smooth, ripple marks, pebbles, rock size) no pebbles Sand ripples 4" x 1½"

Samples Obtained: Type Pipe sample - Sand with sand dollars. ~~Pro~~

Tag Numbers 2 , ______ , ______

How many photos on stake 0

How many photos this dive 0 Photo Numbers ___, ___, ___

Comments

Other tasks performed Set stake & Sample dirt

14
12
10
8
6
4
2

D2

FIELD REPORT
SAN FRANCISCO BAR DREDGE SPOIL DISPERSION STUDY

Towill, inc.

Station No. or Location D buoy ~~#~~ 4

Divers In, Time 13:44 Out, Time 13:47 Date 6-10-71

Diver Johnson Recorded By

Stake Reading Fathometer Depth

Color of Sand Deposited Red + Zircon Visibility, feet 2

Turbidity, materials in suspension Fines in suspension

Catenary and Scope of Buoy Anchor Lines 40°

14
12
10
8
6
4
2

BOTTOM CONDITIONS

1. Marine life, what kind Sand dollars
   Moving or sessile
   In water or on bottom
2. Organic materials (any layer of organic material, sterile bottom or scour)
3. Type of sediment (clay, silt, sand or rocks)
4. Compaction of sediment (penetration easy or difficult)
5. Topography (smooth, ripple marks, pebbles, rock size)

Samples Obtained: Type None.

Tag Numbers ___, ___, ___

How many photos on stake

How many photos this dive Photo Numbers ___, ___, ___

Comments Millions of Sand Dollars on surface. Scouring around nelo- 6" deep. Turbidity heavier near anchor

Other tasks performed Plate was tilted due to entanglement. Some deposit noted. ± 1/2"

D3

FIELD REPORT
SAN FRANCISCO BAR DREDGE SPOIL DISPERSION STUDY

Towill, inc.

Station No. or Location D buoy 4

Divers In, Time 16:09 Out, Time 16:12 Date 6-10-71

Diver ______ Recorded By WDR

Stake Reading ______ Fathometer Depth ______

Color of Sand Deposited ______ Visibility, feet ______

Turbidity, materials in suspension ______

Catenary and Scope of Buoy Anchor Lines ______

BOTTOM CONDITIONS

1. Marine life, what kind ______
   Moving or sessile ______
   In water or on bottom ______
2. Organic materials (any layer of organic material, sterile bottom or scour) ______
3. Type of sediment (clay, silt, sand or rocks) ______
4. Compaction of sediment (penetration easy or difficult) ______
5. Topography (smooth, ripple marks, pebbles, rock size) ______

Samples Obtained: Type ______

Tag Numbers ______, ______, ______

How many photos on stake ______

How many photos this dive ______ Photo Numbers ___, ___, ___

Comments Plate was clear - did not pick up

Other tasks performed ______

14
12
10
8
6
4
2

B1

FIELD REPORT
SAN FRANCISCO BAR DREDGE SPOIL DISPERSION STUDY

nowill. inc.

Station No. or Location Buoy # 4-A stn E

Divers In, Time 9:53 Out, Time 10:15 Date 6-10-71

Diver 4 1 Tresor Recorded By WAR

Stake Reading — Fathometer Depth

Color of Sand Deposited Non. Visibility, feet dark 0'

Turbidity, materials in suspension

Catenary and Scope of Buoy Anchor Lines

BOTTOM CONDITIONS

1. Marine life, what kind

   Moving or sessile

   In water or on bottom

2. Organic materials (any layer of organic material, sterile bottom or scour) Sand dollars under 6" Sand

3. Type of sediment (clay, silt, sand or rocks) 6" loose sand Hard under 6"

4. Compaction of sediment (penetration easy or difficult) med. to 18"

5. Topography (smooth, ripple marks, pebbles, rock size) Could not see some small pebbles

Samples Obtained: Type Sand dollars.

Tag Numbers #1, ,

How many photos on stake 0

How many photos this dive 0 Photo Numbers , ,

Comments Very dark below 15' depth.

Other tasks performed Set sample disk & stake

Picked up sand dollars

14
12
10
8
6
4
2

FIELD REPORT
SAN FRANCISCO BAR DREDGE SPOIL DISPERSION STUDY

E2

Iowill. inc.

Station No. or Location E buoy #4A

Divers In, Time 13:10 Out, Time 13:20 Date 6-10-71

Diver Bob Kennedy Recorded By WAK

Stake Reading ______ Fathometer Depth ______

Color of Sand Deposited red sand only Visibility, feet 3'

Turbidity, materials in suspension none apparent.

Catenary and Scope of Buoy Anchor Lines 45° surface current strong Middle of line almost slack.

BOTTOM CONDITIONS

1. Marine life, what kind Sand dollars on edge - nothing else

   Moving or sessile Noted small sand dollars in groups

   In water or on bottom bottom surface

2. Organic materials (any layer of organic material, sterile bottom or scour) None

3. Type of sediment (clay, silt, sand or rocks) Sand.

4. Compaction of sediment (penetration easy or difficult) —

5. Topography (smooth, ripple marks, pebbles, rock size) Scour noted around anchor 6" deep.

Samples Obtained: Type None

Tag Numbers ______, ______, ______

How many photos on stake 0

How many photos this dive 0 Photo Numbers ___, ___, ___

Comments plate was bare
Sand deposited swept clean during deposit.
No Trouble locating devices

Other tasks performed ______

14
12
10
8
6
4
2

FIELD REPORT
SAN FRANCISCO BAR DREDGE SPOIL DISPERSION STUDY

E3

Towill, inc.

Station No. or Location E

Divers In, Time 16:00 Out, Time 16:03 Date 6-10-71

Diver ______ Recorded By WJR.

Stake Reading .9 Fathometer Depth ______

Color of Sand Deposited — Visibility, feet ______

Turbidity, materials in suspension ______

Catenary and Scope of Buoy Anchor Lines ______

BOTTOM CONDITIONS

1. Marine life, what kind ______

   Moving or sessile ______

   In water or on bottom ______

2. Organic materials (any layer of organic material, sterile bottom or scour) ______

3. Type of sediment (clay, silt, sand or rocks) Sand.

4. Compaction of sediment (penetration easy or difficult) ______

5. Topography (smooth, ripple marks, pebbles, rock size) ______

Samples Obtained: Type None.

Tag Numbers ______, ______, ______

How many photos on stake ______

How many photos this dive ______ Photo Numbers ___,___,___

Comments ______

Other tasks performed ______

14
12
10
8
6
4
2

.9

FIELD REPORT
SAN FRANCISCO BAR DREDGE SPOIL DISPERSION STUDY

Towill, inc.

Station No. or Location F, reset buoy 3A

Divers In, Time 7:03 Out, Time 7:13 7:23 Date 6-18-71 | 14

Diver Erickson Trosor Recorded By WAR.

Stake Reading ______ Fathometer Depth 36'+7' = 43' | 12

Color of Sand Deposited None Visibility, feet 1½' with light

Turbidity, materials in suspension 15 off bottom Turbidity started | 10

Catenary and Scope of Buoy Anchor Lines 55' line | 8

BOTTOM CONDITIONS | 6

1. Marine life, what kind None noted

   Moving or sessile —

   In water or on bottom — | 4

2. Organic materials (any layer of organic material, sterile bottom or scour) None | 2

3. Type of sediment (clay, silt, sand or rocks) Firm sand on surface

4. Compaction of sediment (penetration easy or difficult) 15 blows 3# sledge 18"

5. Topography (smooth, ripple marks, pebbles, rock size) smooth

Samples Obtained: Type None

Tag Numbers ______, ______, ______

How many photos on stake 1

How many photos this dive 1 Photo Numbers 1 test, 2 test, 3 stake, 4 ident.

Comments Divers on bottom could sense surge of long period swell. Bottom current slight.

Other tasks performed Set stake + sampling plate photographic devices in place. Bottom current slight.

FIELD REPORT
SAN FRANCISCO BAR DREDGE SPOIL DISPERSION STUDY

towill, inc.

Station No. or Location F Reset Buoy 3A

Divers In, Time 8:01 Out, Time 8:08 Date 6-18-71

Diver J. G Tresor Recorded By WGR

Stake Reading — Fathometer Depth

Color of Sand Deposited none Visibility, feet

Turbidity, materials in suspension

Catenary and Scope of Buoy Anchor Lines

BOTTOM CONDITIONS

1. Marine life, what kind None

Moving or sessile

In water or on bottom

2. Organic materials (any layer of organic material, sterile bottom or scour) None

3. Type of sediment (clay, silt, sand or rocks)

4. Compaction of sediment (penetration easy or difficult)

5. Topography (smooth, ripple marks, pebbles, rock size)

Samples Obtained: Type hand sample bottom sand, D/O, PH

Tag Numbers 10, 11, 12

How many photos on stake 2

How many photos this dive 2 use. Photo Numbers 5 stake, 6 stake, 7 ident

Comments Plate practically bare

As Biddle passed buoy, dumping was reduced due to hangup in discharge.

Other tasks performed

14
12
10
8
6
4
2

FIELD REPORT
SAN FRANCISCO BAR DREDGE SPOIL DISPERSION STUDY

Towill, inc.

Station No. or Location F Bouy 3A reset

Divers In, Time 10:15 Out, Time 10:24 Date 6-18-71

Diver Erickson Recorded By WDR

Stake Reading ______ Fathometer Depth ______

Color of Sand Deposited ______ Visibility, feet ______

Turbidity, materials in suspension Turbidity

Catenary and Scope of Buoy Anchor Lines

20°-40° off vertical. Taut & slack

BOTTOM CONDITIONS

1. Marine life, what kind None

   Moving or sessile ______

   In water or on bottom ______

2. Organic materials (any layer of organic material, sterile bottom or scour) scour at stake - 6" dia around stake.

3. Type of sediment (clay, silt, sand or rocks) No loose sand.

4. Compaction of sediment (penetration easy or difficult) 2" pipe core, sharp edge 1/8 wall. 20 blows 3# sledge for 18" penetration.

5. Topography (smooth, ripple marks, pebbles, rock size) smooth

Could hand dig into surface sand 14" deep. - probably deeper

Samples Obtained: Type D/O PH + 2" pipe core 18 deep.

Tag Numbers 13, 14, 15

How many photos on stake 2

How many photos this dive 2 Photo Numbers 8 stake, 9 stake, 10, Ident 3

Comments From bottom to 2 ft above bottom, visibility was -1 ft. Above 2' from bottom visibility was 2-2½ ft. No current on bottom.

Other tasks performed ______

14
12
10
8
6
4
2

FIELD REPORT
SAN FRANCISCO BAR DREDGE SPOIL DISPERSION STUDY

Towill, inc.

Station No. or Location F Buoy 3A Reset.

Divers In, Time 11:29 Out, Time ______ Date 6-18-71

Diver G. Trosor J. Recorded By WAR

Stake Reading ______ Fathometer Depth ______

Color of Sand Deposited None Visibility, feet 10 dist above 3' from bottom 1-2' below 3"

Turbidity, materials in suspension Dust particles in suspension can be seen 3' from bottom.

Catenary and Scope of Buoy Anchor Lines ______

BOTTOM CONDITIONS

1. Marine life, what kind 3-4 sand dollars / sq ft Some flat, some on edge.

   Moving or sessile Small jellyfish 1" dia (few) 20' above bottom

   In water or on bottom ______

2. Organic materials (any layer of organic material, sterile bottom or scour) ~~some~~ sterile.

3. Type of sediment (clay, silt, sand or rocks) Sand.

4. Compaction of sediment (penetration easy or difficult) ______

5. Topography (smooth, ripple marks, pebbles, rock size) no rocks sand ripples 3" x ½" deep

Samples Obtained: Type Hand sample bottom sand with sand dollars. D/6

Tag Numbers 16, 17, ______

How many photos on stake 1

How many photos this dive 1 Photo Numbers 11 stake 12, Ident 4

Comments Plate was underscoured + tilted 2:12 slope 0-½" layer on plate.

Anchor of MV Ed Nels is showing scour. Est 3-4" scour

Other tasks performed ______

14
12
10
8
6
4 ← 24
2

FIELD REPORT
SAN FRANCISCO BAR DREDGE SPOIL DISPERSION STUDY

Towill, inc.

Station No. or Location F Buoy

Divers In, Time 12:50 Out, Time 12:58 Date 6-18-71

Diver ~~J~~ G Trotor Recorded By WDR

Stake Reading ______ Fathometer Depth ______

Color of Sand Deposited ______ Visibility, feet 0-1'

Turbidity, materials in suspension Turbidity gradually increasing ~~top to~~ from water surface to bottom Very Turbid on bottom

Catenary and Scope of Buoy Anchor Lines ______

BOTTOM CONDITIONS

1. Marine life, what kind Could not see

   Moving or sessile ______

   In water or on bottom ______

2. Organic materials (any layer of organic material, sterile bottom or scour) sterile

3. Type of sediment (clay, silt, sand or rocks) Sand.

4. Compaction of sediment (penetration easy or difficult) ______

5. Topography (smooth, ripple marks, pebbles, rock size) ______

Samples Obtained: Type D/O PH

Tag Numbers 18, 19, ______

How many photos on stake ± 4 — 13-17 ± stake

How many photos this dive ± 9 Photo Numbers 18-21 Surrounding

Comments Sample plate was clear

White caps & 3 ft waves, fog. Moved in since 12:30

Other tasks performed ______

14	
12	
10	
8	
6	
4	
2	

INCLOSURE 3

TOWILL, INC. REPORT "REPORT ON CURRENT STUDIES
SAN FRANCISCO SAND BAR"

Towill, Inc.

CIVIL ENGINEERS SURVEYORS HYDROGRAPHERS
AERIAL PHOTOGRAPHERS PHOTOGRAMMETRIC ENGINEERS

608 HOWARD STREET, SAN FRANCISCO, CALIFORNIA 94105 • TELEPHONE 415 · 982-1758

SAN FRANCISCO BAR
DREDGED MATERIALS DISPERSION STUDY

Contract No. DACW07-71-C-0063

REPORT ON CURRENT FLOW & PATH STUDIES
1971-1972

A. A. Koch, P.E.

Towill, inc.

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Towill, inc.

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Towill, inc.

REPORT ON CURRENT STUDIES

San Francisco Sand Bar

SECTION 1

INTRODUCTION

DESCRIPTION

The San Francisco sand bar is located on a relatively broad continental shelf about 8 miles seaward of the Golden Gate Bridge. This submerged sand bank is roughly semicircular in plan with depths less than 36 feet. The Bar extends from 3 miles south of Point Lobos to within one-half mile of the shore at Point Bonita; the extreme outer part is about 5 miles west-southwestward of the entrance to San Francisco Bay. The shape and position of the Bar is maintained by a dynamic balance between erosion by tidal flows and buildup by coastal currents. All this material is derived from erosion of coastal cliffs and outwash of streams. The material is transported to the Bar, from the north, by longshore coastal currents. No measurable part of the sand bank is derived from the San Francisco Bay system itself. It is believed that the sediment outflow by tidal flows is conveyed out over the Bar into deepwater. The result is a submerged bank maintained by longshore sediment transport and held offshore by an ebb tidal prism.

The San Francisco Bar has been dredged for a deep-draft (50 feet) navigation channel. Current project deepening to 55 feet was authorized and dredging to that depth has been initiated recently.

ENVIRONMENT FOR SAND MOVEMENT

Reduced to most simple terms, the effect on the regional environment of applying additional material on San Francisco sand bank is the determination of the direction and magnitude of hydraulic forces acting on the mass. Experiments and observations have indicated that movement of water deposited material will not occur until a critical (threshold) stress is exceeded. Simply expressed, such movement will not take place until the drag of a grain of the material that holds it in place is overcome by a local hydraulic force. Observation shows that instantaneous local fluid velocity required to move a particle may be many times the measured average hydraulic velocity.

Because of the relatively shallow water depths at the proposed disposal site, considerable turbulence may frequently be anticipated. Such turbulence, acting in conjunction with the various currents and with the poor settling properties of much of the dumped material, will frequently tend to transport some of the dumped material considerable distances from the points of disposal. Coastal currents rarely flow at uniform and even velocities and directions, especially in the more shallow depths. Light weight material will obviously be transported further than heavier materials.

MOVEMENT OF SEDIMENT

As was briefly discussed above, to move sediment the local velocity must exceed some critical value, although its magnitude is not clearly defined. The needed motion can be created in two ways: either by waves (orbital velocity); or by currents. The precise mechanism of bar formation and movement by the various types of waves and oscillatory flow is not yet well understood.

For material heavier than water to remain in suspension in the open sea, there must exist adequate energy in the form of turbulence to overcome the rate of gravitational settling. In a calm sea, the distance a material of a given sand grain size may travel in suspension is related to the mass transport of the area.

It is frequently observed at San Francisco Bar (and during diving operations in June, 1971), that in moderate and heavy seas, the water in the relatively shallow water over the submerged sand bank appears to be highly charged with fine sediment. Although the suspended material may have had a littoral origin as a result of coast erosion, it is also probable that some of the fine suspended substance may have been stirred up from the Bar itself by waves of critical size (the chop so frequently encountered there). In water of shallow depth, wave-created oscillations may at times exceed the velocity of currents caused by tides. Sediment transport near the top of the sand bar may take the form of sliding, rolling, intermittent suspension of larger particles as well as a mass transport process.

OCEANOGRAPHIC SEASONS

Nearshore currents in the region of the San Francisco sand bar are related to and partially are a consequence of the general pattern of circulation of the Pacific Ocean. The seasonal variations and the degree of influence on the Bar are yet to be determined.

Ocean water flows in an eastward direction from Japan between latitudes 45°N and 50°N. On approaching the West Coast of North America, the flow divides and the branch going downcoast along the shores of Oregon and California is termed the California Current.

In Spring and early Summer, the prevailing winds are northwest off the coast of California. As a consequence of the California Current, the force of the northwest winds and Coriolis force (effect of the earth's rotation on a moving body), a portion of the surface water is turned seaward and replaced in part by subsurface water. This is termed the Upwelling Period and usually occurs between February and July.

Following the period of upwelling, generally between July and November, is known as the Oceanic Period. It is characterized by irregular eddies and current patterns of a complex nature. In some nearshore areas, the Oceanic Period is not strongly evident until September and, in these areas, the time interval between July and September is termed the Summer Period characterized by some upwelling and some current eddies and other irregularities. In general, it reflects a period of gradual transition for the Upwelling Period to the Oceanic Period over an interval of two or three months.

Usually in November, a strong countercurrent to the California Current develops between the shore and the current known as the Davidson Current. The counter-current flows northerly along the coastline until January or February and is termed the Davidson Period.

The oceanic periods discussed above are summarized in the following tabulation:

Seasonal Period	Months
Upwelling	February to July
Oceanic	July to November
Davidson	November to February

COASTAL CURRENTS

Classification of Flow - Ocean and coastal currents may be classified into the following general groups, namely:

1. Currents that are related to the distribution of density in the sea;
2. Currents that are induced by the stress of wind on the sea surface;
3. Currents and transport induced by surface gravity waves;
4. Tidal currents and currents generated by internal waves, and;
5. Local currents induced by fresh water entering the ocean at river mouths.

Concerning the above classification of currents, group (1) is a large-scale phenomenon, probably not of importance to the immediate problem, and for group (5) no data for the dredged material disposal site are known to be available.

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Wind-Induced Surface Currents - When wind blows over the surface of the ocean, a stress induces a shallow wind drift creating a transport of water which alters the density distribution and corresponding currents. In the Northern Hemisphere, the total transport in the open sea due to wind drift is directed at right angles to the wind. Near the coasts, however, modifications occur that cause secondary effects of the wind to become important. For a wind parallel to the coast, in some instances, the effect of the wind causes a transport of surface water toward the coast.

It has been observed at the former San Francisco Lightship (37°45.0'N., 122°41.5'W.) that the average velocity of the current due to winds of various strengths may be estimated as shown in the following tabulation and are assumed to apply approximately to the San Francisco sand bar area:

Wind Velocity (miles per hour)	Average Current Velocity (knots)
10	0.3
20	0.3
30	0.5
40	0.6
50	0.7

The position of the shoreline with respect to the station influences considerably the direction of the currents due to certain winds. The following table shows the average number of degrees by which the wind-driven current is deflected to the right or left of the wind. Thus, at San Francisco Lightship site, the table indicates that with a north wind, the wind-driven current flows on the average 061° west of south, and with an east wind it flows 023° north of west.

Wind From	Left	Right
	°	°
N		061
NNE		027
NE		030
ENE		031
E		023
ESE		029
SE		021
SSE		005
S	020	
SSW	030	
SW	049	
WSW	051	
W		033
WNW		016
NW		017

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Surface Gravity Wave-Induced Currents - Waves of this group are generally the most important factors in the coastal process as they tend to determine the characteristics of a beach. Such waves create currents, called "littoral transport", that move sand along a coast. The littoral current acts in conjunction with the agitating action of breaking waves to move material up or down a coast.

Prevailing Wind and Waves - The prevailing direction of winds and swell is from the northwest although during the winter months there is sometimes a heavy swell from the southwest. Storms in winter occur often and suddenly and few storms occur in summer. Most storms are from the north and northwest. The occasional storms from southeast to southwest are considered the most dangerous to small craft.

The predominant offshore wave approaches the coast from the west-north-west and has a significant wave period of 12 seconds. Wave refraction studies indicate that waves reaching San Francisco sand bar from the south and southwest are not affected by the Farrallon Islands. Waves that reach the Bar from the west through northwest directions are partially shielded by the Islands and broken into separate wave trains with extensive caustic areas. In general, waves from the west through northwest tend to be slightly reduced in height due to the loss of wave energy at the Farrallones and in the landward caustic areas. However, studies indicate that these are selective directions and wave periods for which orthogonal focusing may cause increase in wave heights.

Hindcast deepwater wave data for statistical wave station No. 3 are available. This station (37.6°N., 123.5°W.) is located about 60 miles west of San Francisco. The highest waves at this deepwater location come from a west to northwest direction.

Table 1 presents the average number of hours per month in which waves (both sea and swell) in excess of 1.0 ft. high occur from various directions for Wave Station No. 3. Also shown in this tabulation are the height, period, and direction of the maximum wave that occurred during each month.

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TABLE 1

Duration of Sea and Swell in Excess of 1.0 ft.
at Wave Station No. 3
(Lat. 37.6°N, Long. 123.5°W)

Month	Duration (hours)				Maximum		Wave Direction
	SW	SSW	S	SSE	H (ft.)	T (Sec.)	
Swell							
Jan.	1	12	13	-	10.9	10-12	S
Feb.	48	4	2	-	10.9	8-10	SW
March	-	11	17	-	8.9	8-12	S
April	24	-	-	-	2.9	8-12	SW
May	-	6	20	2	8.9	10-14	SW
June	-	-	-	-	C**	-	-
July	-	-	-	-	C	-	-
Aug.	-	-	-	8	2.9	10-16	SSE
Sept.	46	-	-	-	2.9	8-10	SW
Oct.	-	-	-	-	C	-	-
Nov.	-	-	-	-	C	-	-
Dec.	-	-	11	-	4.9	6-14	S
Sea							
Jan.	56	29	84	88	14.9	10-12	SSW-SSE
Feb.	71	41	106	35	18.9	10-12	SSW
March	52	12	59	20	18.9	10-12	S
April	25	12	41	22	12.9	8-10	SW
May	50	13	67	14	3.9	12-14	SW
June	12	-	8	-	4.9	4-6	SW-S
July	8	2	-	-	4.9	4-8	SW-SSW
Aug.	-	-	4	-	2.9	4-6	S
Sept.	22	2	17	4	10.9	8-10	S
Oct.	40	2	46	20	8.9	6-8	S-SSE
Nov.	17	8	28	12	4.9	4-8	SW-SSE
Dec.	46	10	26	37	8.9	8-10	SSE

C**= Calm - less than 0.9 ft.

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Littoral Transport - The predominant direction of littoral transport along the coast of central California is downcoast. However, littoral studies using tracer techniques show that the littoral current migrates from north of the Golden Gate around the seaward side of San Francisco sand bar and enters Ocean Beach in front of Fleishhacker Zoo and then downcoast. Between the Zoo and Point Lobos, the littoral current may flow either north or south depending on the season of the year. Figure 1 shows the general pattern of direction of littoral drift in the general region of the San Francisco sand bar.

Tidal Currents and Coriolis Force - Currents generated by the tides in the vicinity of San Francisco sand bar are, of course, related to the astronomical forces of the moon and sun. These tidal forces operate in conjunction with local hydrographic features to produce tidal currents characteristic of a particular locality.

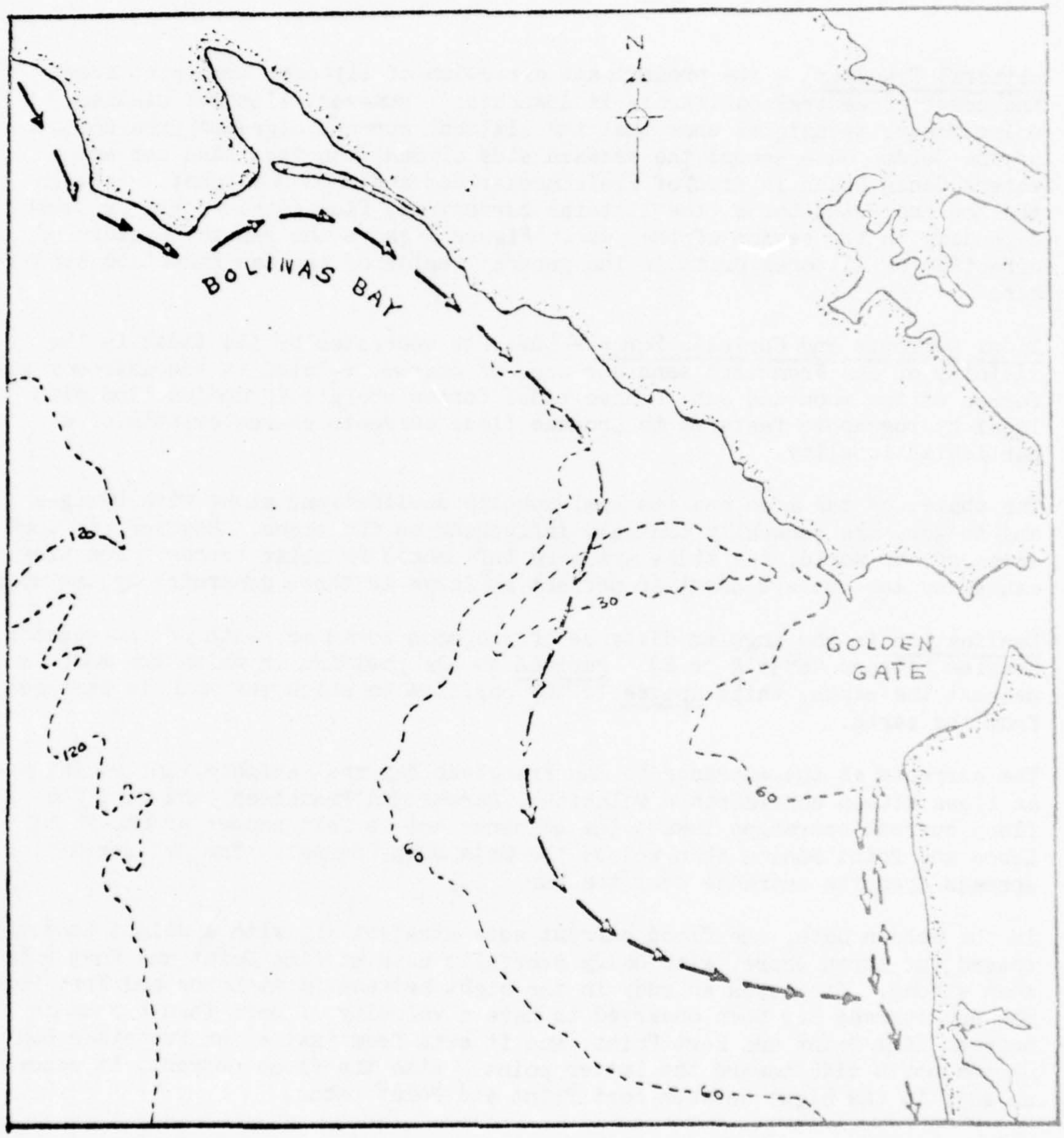
The phases of the moon and its semi-monthly declination, along with Perigee and Apogee, are generally the main influences on the tides. However, in some areas of the world, the tides are more influenced by solar forces. The tides caused by the sun are about 46 percent as large as those generated by the moon.

Declination is the angular distance of the moon north or south of the equator (varies between 28°35'N or S). Perigee is the position in which the moon is nearest the earth, while Apogee is the position in which the moon is farthest from the earth.

The currents at the entrance to San Francisco Bay are variable, uncertain, and at times attain considerable velocity. Across San Francisco sand bar, the flood current converges toward the entrance and is felt sooner around Point Lobos and Point Bonita than across the Main Ship Channel. The ebb current spreads from the entrance over the Bar.

In the Golden Gate, the flood current sets straight in, with a slight tendency toward the north shore, with heavy overfalls both at Lime Point and Fort Point when strong. It causes an eddy in the bight between Point Lobos and Fort Point. The ebb current has been observed to have a velocity of more than 6.5 knots between Lime Point and Fort Point, and it sets from inside San Francisco Bay on the north side toward the latter point. Like the flood current, it causes an eddy in the bight between Fort Point and Point Lobos.

Published velocities of tidal current (Golden Gate) are average velocities. Near the time when the moon is full or new, the velocities are about 20 percent greater than the average, and near the times of the moon's first and third quarters, the velocities are smaller than the average by 20 percent.



DIRECTION OF LITTORAL DRIFT

Source: Kamel and Corps of Engineers, B.E.B.T.M., No. 131

FIGURE 1

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Figure 3 shows the maximum ebb tidal current in the vicinity of the Golden Gate. On Figure 4 are indicated the maximum flood tidal currents for the same general area. It seems likely that at the dredged material disposal site, the ebb currents may also be greater than flood tidal currents.

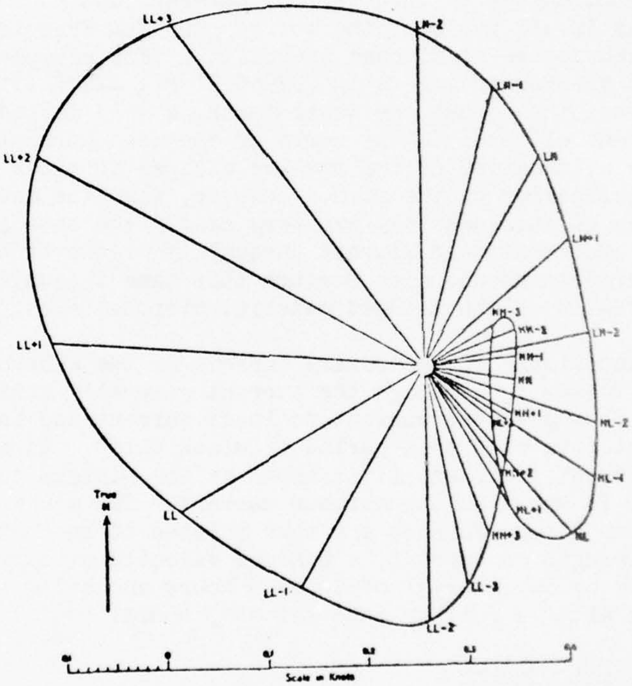
The rotational character of the tidal currents (due to Coriolis force) in the coastal waters near the entrance to San Francisco Bay has long been observed. This motion is not unique to this region, however, but has occurred in tide-affected regions in all parts of the world. Off San Francisco Bay, the current exhibits a marked degree of diurnal inequality. For example, a long series of observations at the former lightship (37°45.0' N., 122°41.5'W.) have shown, see Figure 2, that throughout the lunar month, a very marked difference in size of the two current ellipses in the curve of the mean current infers a very nearly complete elimination of the smaller ellipse at times of the extreme semi-monthly declination of the moon. However, when the moon is over the equator, the two ellipses of the lunar day are very nearly the same (Marmer). Therefore, because of the aforementioned diurnal inequality of the tide at San Francisco, the offshore currents should also feature this same inequality to a considerable degree in the region of the dredged material disposal area.

A feature characteristic of the rotary current is the absence of slack water (Tidal Current Tables). Although the current generally varies from hour to hour, this variation from greatest current to least current and back again to greatest current does not give rise to a period of slack water. When the velocity of the rotary tidal current is least, it is known as the minimum current, and when it is greatest, it is known as the maximum current. The minimum and maximum velocities of the rotary current are thus related to each other in the same way as slack and strength of current, a minimum velocity of current following a maximum velocity by an interval of about 3 hours and being followed in turn by another maximum after a further interval of 3 hours.

CURRENT OBSERVATION PROGRAM

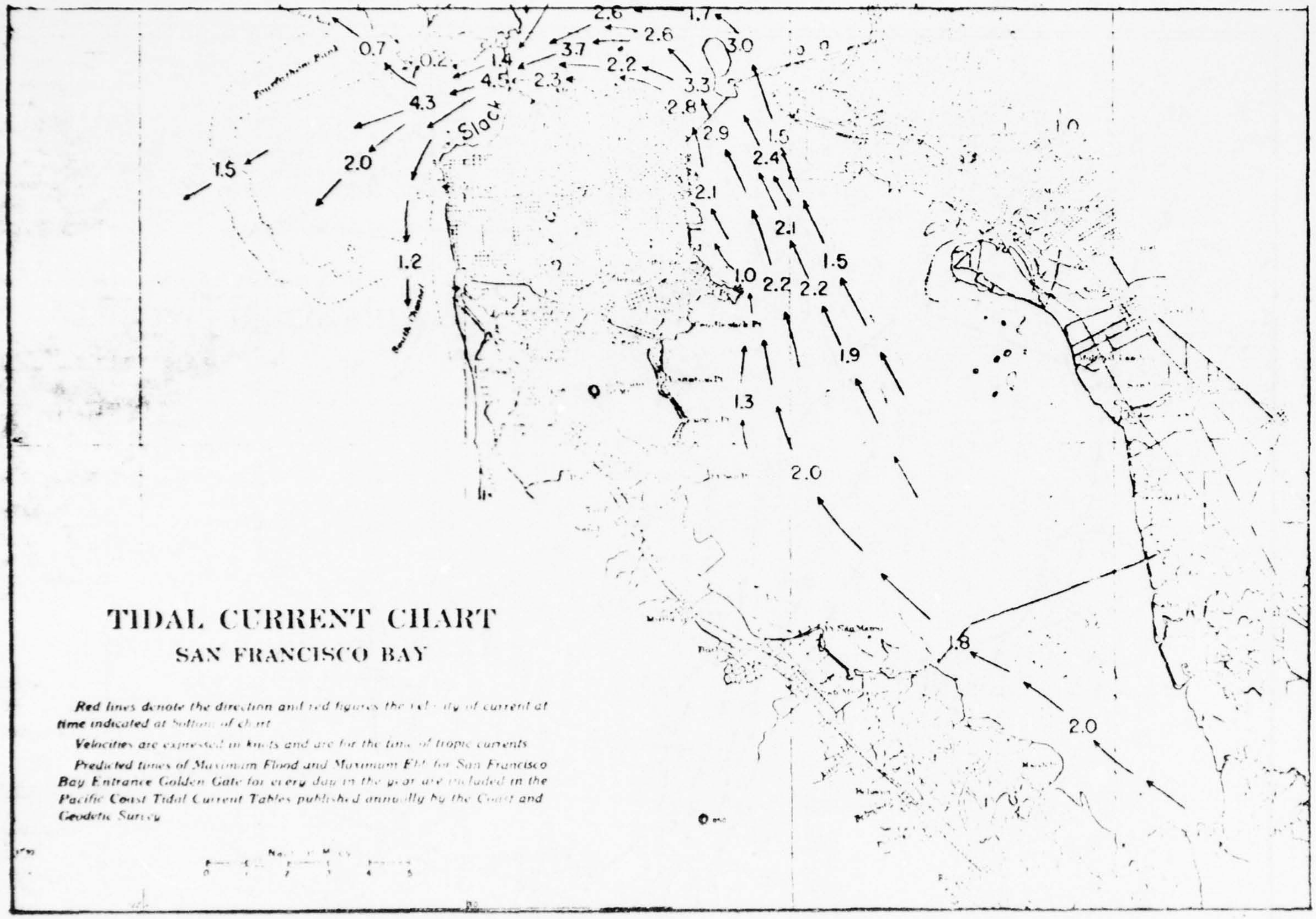
Types of Studies - Two types of current studies, flow and path, were employed in this investigation. The current flow is measured from a fixed position while the other tracks a unit value of water in its path.

Current flow measurement utilized a Savonius-type velocity and direction observing device, fixed at approximate position (37°46'N., 122°36'W.) on June 7-8, 1971. Flow was measured for depths of 1, 6 and 12 meters below surface from an anchored vessel. Each measurement was of 10-minute minimum duration during major current phases of the lunar day.



Mean Current Curve, San Francisco Light Vessel

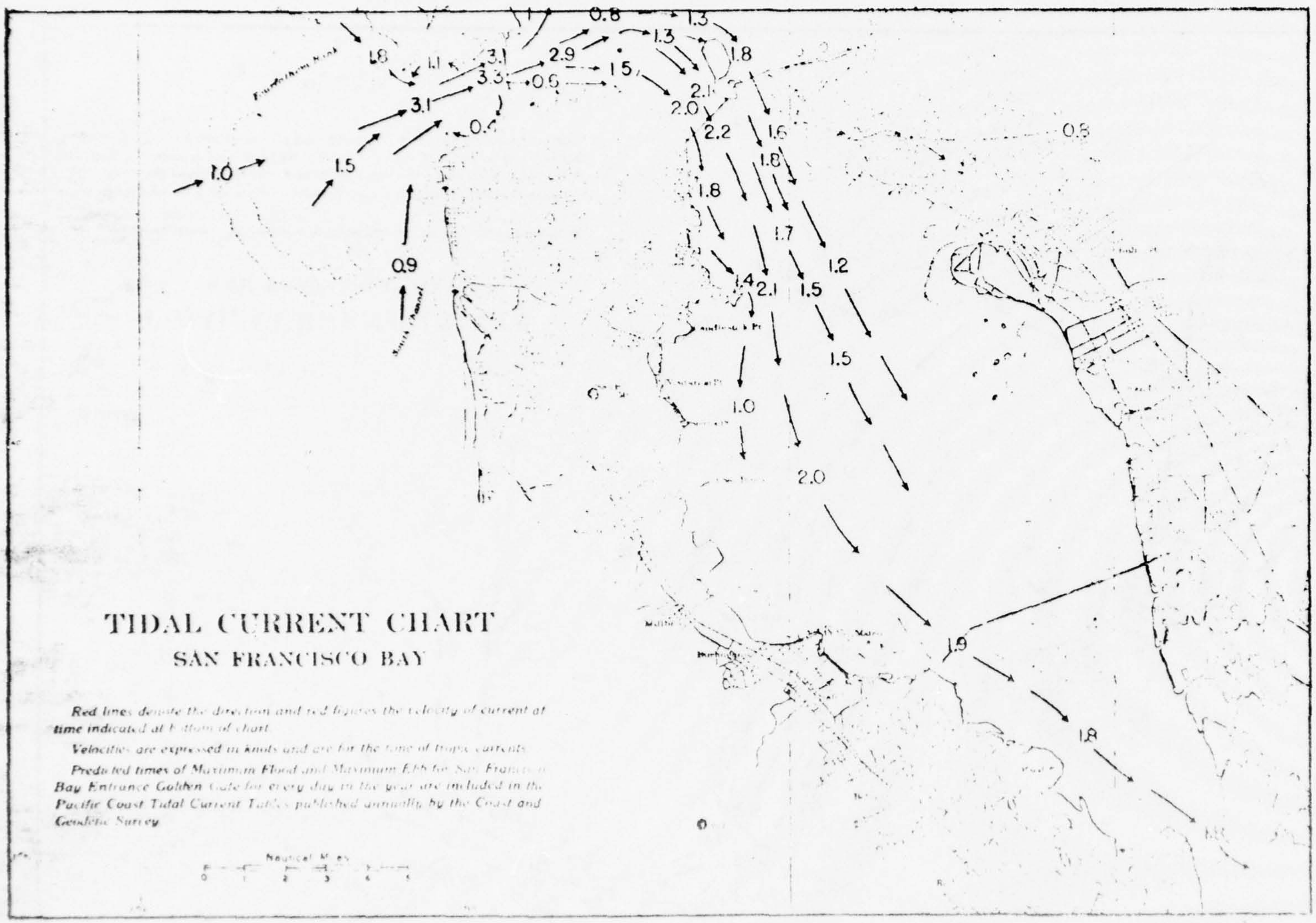
FIGURE 2



MAXIMUM EBB AT GOLDEN GATE

FIGURE 3

Source: Tidal Current Charts, U.S.C. & G.S.



MAXIMUM FLOOD AT GOLDEN GATE

Source: Tidal Current Charts, U.S.C.& G.S.

FIGURE 4

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Current path measurements were obtained by launching a free running drogue at the same location (37°46'N., 122°36'W.) as the flow current studies. The drogue was equipped with a radar reflector and its position determined at frequent interval by bringing the research vessel alongside the drogue. The position of the vessel was then determined by use of shipboard radar, as discussed in Section 4.

As desribed earlier in this section of the report, the path determinations were timed to sample each of the three oceanographic seasons, namely: Upwelling, Oceanic and Davidson.

SECTION 2

PURPOSE OF DROGUE STUDIES

OBJECTIVE

The primary purpose of experiment, of course, is to attempt to determine the relative influence of a phenomenon. A proper description of the fluid motion, such as presented by a drogue path, necessarily involves determining the space-time characteristics of velocity and acceleration. The main concern on the sand bar is with flow velocity which is the time rate of displacement of a point, a vector quantity. The velocity vector at a point in the drogue path is the vector sum of the components.

At the San Francisco sand bar, the objective of the series of tests was to delineate the hydraulic factors influencing the mass water patterns in the disposal area. Nearshore currents in the vicinity of the test site ($37^{\circ}46'$N., $122^{\circ}36'$W.) are probably influenced to some degree by the general patterns of water circulation of the North Pacific Ocean in the several oceanographic seasons discussed earlier in this report. The seasonal influences were to be determined by proper scheduling of the experimental test periods.

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SECTION 3

CURRENT MEASUREMENT BY DROGUES

CONCEPT OF DROGUE USE

In the investigation of hydraulic forces acting at San Francisco sand bar for the Upwelling, Oceanic, and Davidson oceanic periods, use was made of drogues set at fixed depth. Continuous recordings were made of path position, current speed and direction by tracking a passive reflector equipped drogue. The program of locating drogue position is described in Section 4.

The drogue method of measuring current speed and direction has become increasingly important as a means of obtaining oceanographic data by the United States Navy. "The path followed by the drogue will be that of the general water mass, and internal waves or minor current fluctuations generally will not be reflected; however, by recording positions at more frequent intervals rotary tidal currents and changing current patterns can be detected".*

DEPTH OF DROGUE

Drogues have been used by the Pacific Gas and Electric Company in its investigations of the effect of proposed thermal power plants on the marine environment. The drogue was set at a depth of 15 feet at the Mendocino site (1970) and also at the Davenport site (1970). It is the opinion of the Consulting Oceanographers, employed on the San Francisco Bar Study, that drogue results obtained at a depth of 15 feet yield a reasonable representation of the average water column velocity.

*U. S. Naval Oceanographic Office,"Instruction Manual for Obtaining Oceanographic Data", Pub. No. 607, 3rd Ef., Chapter M, (Change-1-1970).

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SECTION 4

LOCATION OF DROGUE DURING PATH SURVEY

FIELD OPERATION

At the point of launching and recovery, and at periodic intervals during the survey, the drogue was located by radar positioning of the tender vessel. At the time of each "fix", the tender vessel was maneuvered close to the drogue, and the location of the vessel was considered to be the location of the drogue. Between fixes, the drogue was monitored by radar, and the vessel followed the drogue's path to ensure that the drogue could be located at the next "fix" time.

At each "fix" position, the bearing and distance to three identifiable shore features was recorded, along with the time, wind velocity and direction, and depth. Distance was measured by interpolating the distance rings on the radar display. Bearing to each shore station was determined by simultaneously observing, with the radar curser, the angular value of the shore position relative to the zero settling of the curser, and the magnetic heading of the vessel, as indicated by the vessel's gyro stabilized compass. By adding these two values, the magnetic bearing of the line from the vessel to each shore station was determined. After completion of each "fix", the drogue's position was plotted on USC&GS hydrographic chart No. 5502 (scale 1:207,840), using the method of intersecting bearing lines.

OFFICE PLOTTING

All fix positions were later office plotted on an overlay of USC&GS chart No. 5072 (scale 1:100,000), using a combination of bearing and distance intersections. With field record of three lines in bearing and distance, a total of 10 separate position solutions is possible.

3 point intersection	1 solution
Bearing line intersection	3 solution
Distance line intersection	3 solution
Single bearing & distance	3 solution
TOTAL	10 solution

Assuming that no significant errors in observing or recording are made, the strength of each solution is dependent upon:

1. The probable accuracy of distance
2. The probable accuracy of radar angle
3. The probable accuracy of compass bearing
4. Strength of geometric figure
5. Chart accuracy
6. Position drift during observation
7. Plotting scale.

During the field operation, plotting was done on a small scale chart, using the method of bearing intersection.

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Office plotting included an analysis of all possible methods on selected points, and review of the final office plots indicated significant variations from the field plats.

The plotting analysis indicated that an apparent lag of the gyro stabilized compass, under some conditions, contributed bearing errors of up to 10°. This lag cannot be considered constant for all readings on any fix, probably because changes in the rate of rotation of the vessel during observations introduces varying lag influence.

As a result of this indicated lag, it appears appropriate to assign greater weight to the distance measurements; however, the bearing data can be considered as useful supporting information.

The final plots of the drogue track, as submitted with this report, indicate a probable accuracy in positioning as shown in the following summary:

Within 1/10 nautical mile	60%
Within 2/10 nautical mile	25%
Within 3/10 nautical mile	13%
Within 4/10 nautical mile	2%.

The above is based on the deviation from the mean of all plotted positions from each fix, and does not include any constant or systemmatic error of the radar display.

In comparing the field plots to the office plots of the drogue track, difference in fix positions, especially on the June 25, 26 survey, were noted. In analyzing these differences, the major causes were:

1. Reliance on bearing fixes, in the field plot, vs. combined distance and bearing solutions.
2. Interchanging shore point identifications in field notes (isolated by office analysis).
3. Misidentification of shore position. (This was cause of major discrepancy in June 25, 26 survey.)

SUMMARY AND COMMENTS

Procedure used for location of drogue fixes can yield results within 1/10th nautical mile ± inherent error of radar system.

Radar reflection array on drogue is satisfactory; however, in higher sea states, radar "clutter" from waves obscures the reflector signal. Under this condition, the drogue must be followed closely so that radar or visual contact is constantly maintained.

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Other positioning techniques, such as sextant, intersection by survey from shore stations, microwave range-range distancing (autotape, etc.) are reliant upon geometric strength of figure and/or weather condition. For the subject area, it appears that radar positioning is adequate for the purpose, as it requires no pre-surveyed shore positions, is the simplest system available. Extreme care must be exercised in obtaining and recording range and bearing data, and it is suggested that a Polaroid camera, specifically designed for cathode ray tube photography, would provide an exact record from which fix locations could be plotted at any convenient scale.

SECTION 5

RESULTS OF CURRENT MEASURING TESTS

SCHEDULE

Current measuring studies in the general area of the San Francisco sand bar were conducted in each of the orographic seasons as indicated below:

Date of Test	Oceanographic Season
June 7-8, 1971	Upwelling
June 25-26, 1971	
October 1-2, 1971	Oceanic
November 5-7, 1971	
February 1-2, 1972	Davidson

Current velocity and direction measurements as a function of depth were made for one station (June 7-8, 1971) and the current path study was based on drogue release of the same station. Meterological and sea state conditions during each drogue test were also observed.

Temperature, salinity and water density data were acquired during the test cycle for June 8, 1971, at the surf and at depths of 18 and 36 feet.

JUNE 25-26, 1971 TEST PERIOD

A free running drogue was set to a depth of 15 feet and released in the immediate vicinity of Buoy No. 7 ($37^{o}46$'N., $122^{o}36$'W.) at 22:30 (June 25, 1971). The test ended at 22:30 (June 26) and the path travelled between the beginning and end points is shown as Figure 5.

From the starting point to 16:30 (June 26) the current path is rotatory in a generally clockwise sense. From 16:30 (June 26) to the end of 22:30 the path reverses direction of rotation to become generally counter-clockwise in a tight loop in comparison to the previous portion of the cycle. During the entire period of the test, wind and wave-generated currents probably had negligible effect on the drogue's path. The hydraulic forces acting on drogue are believed to have been primarily tidal acting concurrently with coastal currents, of unknown magnitude and direction, typical of the Upwelling Season.

The period of test was about three days after new moon and its declination was north of the equator and approaching Apogee (June 30) resulting in a highest tide of 5.5 feet and a lowest tide of -0.6 feet. A breakdown of drogue path

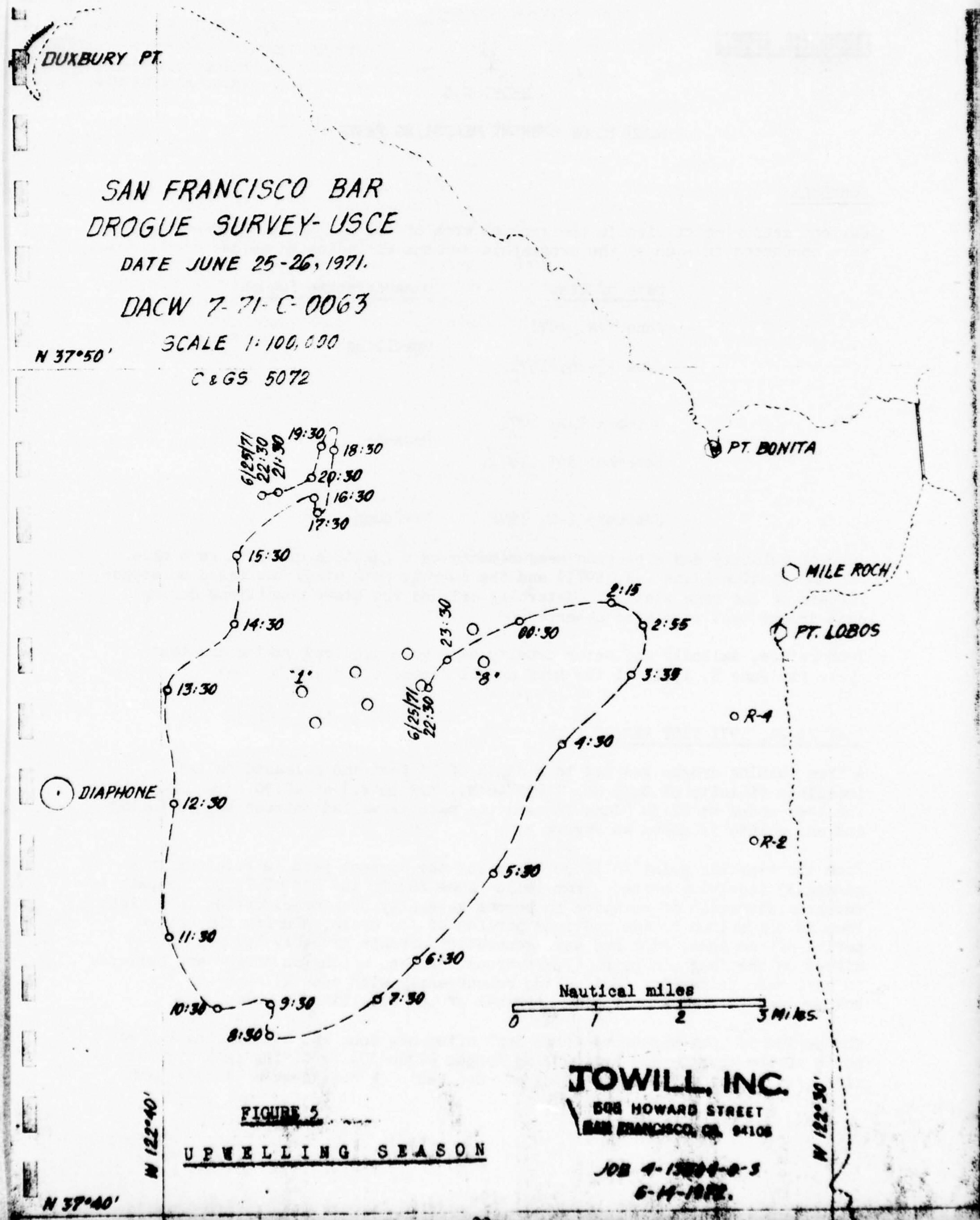

FIGURE 5

UPWELLING SEASON

characteristics is shown in Table 1-A, Appendix A.

The greatest velocity of the drogue occurred approximately 3 hours after HH (or about 3 hours before LL), and again at approximately 3 hours after LL (or about 3 hours before LH).*

NOVEMBER 5-7, 1971 TEST PERIOD

A drogue was released at 23:00 on November 5, 1971, during the flood portion of the tide cycle following an extreme low (-1.4 feet at 19:36). The moon had been full, near Perigee, and north of the equator two days previously. During the test period, tides varied from a maximum of 6.1 feet to a minimum of -1.0 feet, a change of 7.1 feet in about seven and one-half hours. It would be expected, therefore, that strong ebb and flood tidal currents might be created by the large differential of head in the Golden Gate entrance.

During the drogue test period, strong southerly directed ebb currents developed as shown in the following tabulation.

Day (November 1971)	Time	Velocity (knots)	Direction	Distance from ℄ Golden Gate Entrance (Nautical mile)
6	6:00-6:30	2.2	SSW	2 to 3
6	16:00-17:00	2.9	SSE	3 to 4
7	20:30-21:00	2.1	SSW	10 to 11

This test period was typical of the Oceanic Season characterized by irregular eddies and current patterns of a complex nature as shown on the drogue plot Figure 6. Although the general drift of the drogue was clockwise, there are two distinct periods of confused and erratic motion.

About three hours after release, the drogue entered the Golden Gate on the crest of the flood inflow current and for several hours drifted erratically in the vicinity of Mile Rock and Point Lobos. From 5:00 to about 7:00 (November 6) the drogue path reflects the strong tidal prism outflow current from San Francisco Bay.

From approximately 7:00 to 16:00 on November 6, the drogue path was erratic and variable in velocity and direction. From 16:00 (November 6) to about 5:00 (November 7), the motion was a generally rotary path in a clockwise sense.

*HH = highest tide
LL = lowest tide
LH = lowest high
HL = highest low

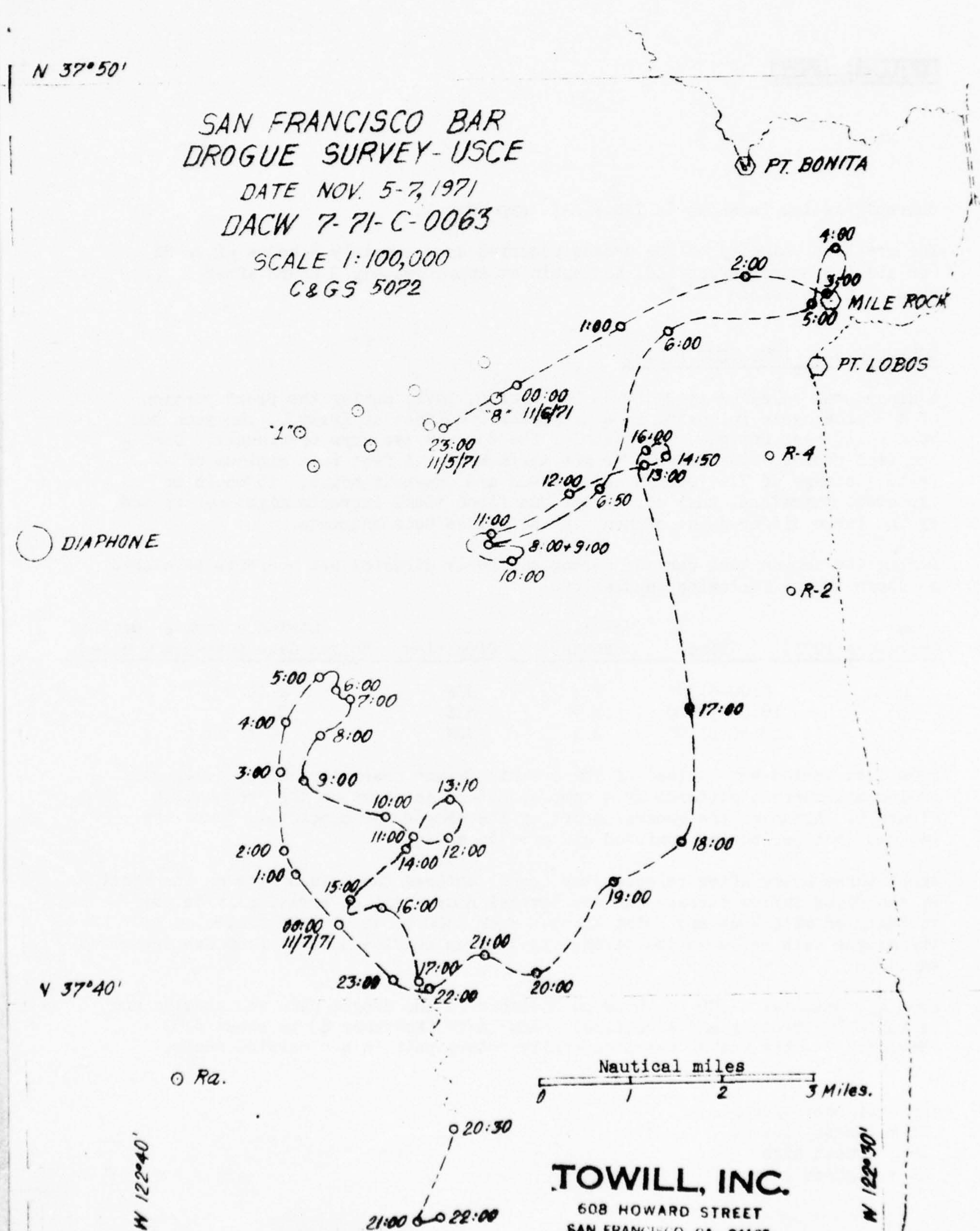

FIGURE 6

OCEANIC SEASON

From 5:00 (NOvember 7) to the end of the test, the drogue path was somewhat erratic and moved generally downcoast. As noted in the tabulation above, a relatively high ebb current flow (2.1 knots) occurred near the end of the drogue path off Pacifica, about 10 to 11 nautical miles south of the Golden Gate entrance.

A breakdown of drogue path characteristics is given in Table 2-A, Appendix A.

FEBRUARY 1-2, 1972 TEST PERIOD

A drogue was released on February 1, 1972, at 11:40 in the immediate vicinity of Buoy No. 7 (37°46'N., 122°36'W.). The test ended on February 2, 1972, at 19:20. The device was set to float at a depth of 15 feet.

On February 2, 1972, the moon was on the equator, full moon having occurred on January 30. During the test period, the highest tide at the Golden Gate was 5.5 feet while the lowest tide was 0.0 feet, both on February 1.

With reference to Figure 7, to an observer stationed at the starting point, the motion of the drogue would have appeared to have been predominantly clockwise with the greatest velocity during the first 20 minutes after the drogue's release. Between 20:00 (February 1) and 7:00 (February 2) the path was very erratic and the motion was confused, both in magnitude and direction. After 7:00 (February 2), the drogue resumed a more regular generally clockwise path.

The period of erratic and confused motion could not have been noticeably influenced by waves because during that time interval there existed a calm sea state. It is conjectured that it perhaps pictures a complex transition area of eddies between an offshore southward California Current and an inshore northward Davidson Current.

After 15:00 on February 2, the wind and waves increased from the eastward and may have influenced the drogue to move generally seaward due to wind and wave induced currents and strong ebb currents acting concurrently.

Table 3-A, Appendix A, presents a breakdown of the drogue path characteristics for this test period.

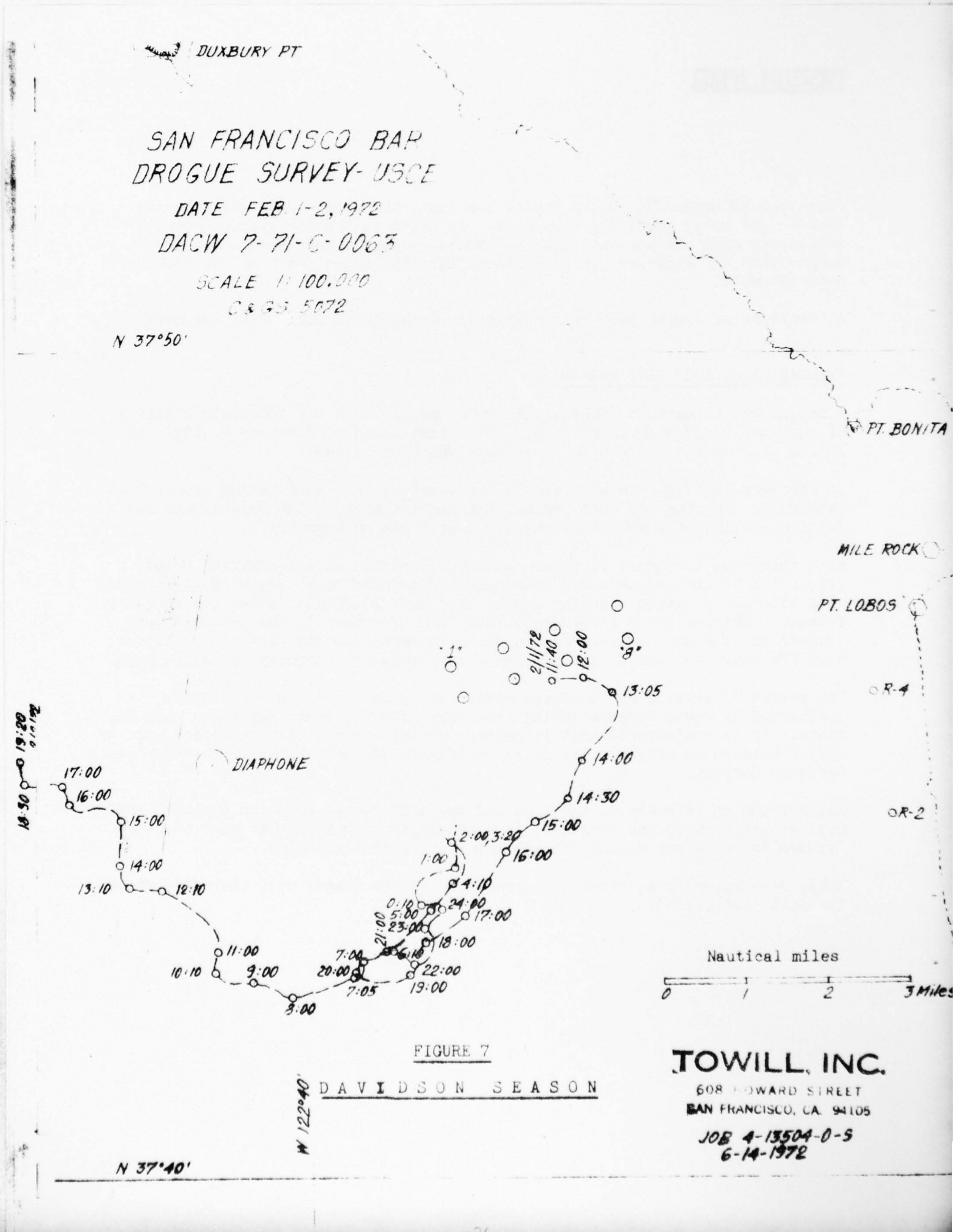

FIGURE 7

DAVIDSON SEASON

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CORRELATION ANALYSIS AND COMPARISON OF PATHS

Correlation Analysis - The current measurements of June 7-8, 1971 were analyzed, in a preliminary way, to determine depth representing an average velocity for a uniform velocity gradient and to determine a possible correlation between observed velocity and published tidal velocities for the Golden Gate.

For the test station (37°46'N, 122°36'W), the computations show that the depth for average flow is about 20 feet below the surface. This represents 0.45h from the surface where h=depth as measured on June 7-8, 1971.

The correlation study, by the simple rank difference method, indicated that a positive and satisfactory relationship existed. For example, for flood tide, the following ratios were obtained.

Depth (meters)	Coefficient (P)
6	0.706
12	0.727

Relationships such as these infer that published tide currents may perhaps be employed to predict currents at the San Francisco sand bar for a variety of conditions. Correlations would probably improve for non-linear analysis and reliable prediction equations might be developed for estimating conditions at the Bar throughout the year.

Comparison of Paths - A gross feature common to each of the drogue studies in June and November, 1971, and February, 1972, was the generally clockwise rotation of the tidal current. This type of tidal current motion had previously been known to exist from a long series of observations at the former San Francisco lightship (37°45.0'N, 122°41.5'W). The current at that location exhibited a marked degree of diurnal inequality. The size and shape of the roughly elliptical path varied throughout the lunar month with phases of the moon and its declinations.

Comparative features of the three drogue path periods are presented below:

Test Period	Limits of Rotary Motion* South	West	Oceanographic Season	Maximum Current Knots	Direction
June 25-25,1971	6	6	Upwelling	1.7	SSW
Nov. 5-7, 1971	8	5	Oceanic	2.9	SSE
Feb. 1-2,1972	6	10	Davidson	1.2	ENE

* Nautical miles from centerline at Golden Gate entrance

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TIDAL CURRENT PREDOMINANCE

The Consulting Oceanographers analyzed the flow measurements of June 7-8, 1971 taken at a fixed location (37°46'N., 122°36'W.). Their computations indicated that in general the ebb currents exceeded the flood currents. However, the ebb predominance was not detectable at the surface, but did appear to exist at depths of 6 and 12 meters.

With regard to the several drogue path studies, it was observed that paths were predominated by a clockwise rotary motion. This type of motion had also been observed to exist at the location of the former San Francisco Lightship (37°45.0'N., 122° 41.5'W.).

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SECTION 6

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The current velocity and direction measurements and the several successful drogue path observations have resulted in considerable basic data of much value to the study of hydraulic forces at work on the San Francisco sand bar. Further analyses of these data in relation to the dredged material disposal site are required to make sound engineering judgements of the effects of depositing material on the ship channels and on the marine environment of the general region. A study of the paths themselves gives only a rough picture of what is occurring dynamically on the sand bar. It would be desirable, for a better understanding of the nature of hydraulic forces at work, to undertake a thorough analysis of the magnitudes of local velocities and accelerations of the moving fluid.

Additional current velocity and direction measurements at other critical locations on the Bar, and further refined correlation of existing tide current and wave hindcast data might lead to a means of predicting the hydraulic forces at work on the submerged sand bank throughout the year utilizing weather forecasts and published tide currents information. The literature, both domestic and foreign, dealing with this complex subject, is extensive and a thorough review of available knowledge would probably be of much benefit in obtaining satisfactory solutions to the problems of environmental effects of depositing dredged material on San Francisco Bar.

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RECOMMENDATIONS

The San Francisco sand bar appears to be in approximate equilibrium as a result of the prevailing wave action which tends to move sediment eastward toward the Golden Gate and the tidal currents which occur during ebb flows from San Francisco Bay and tend to move sediment westward (Johnson). As with other submerged sand banks, the Bar represents a superfluidity of material on the floor of the ocean shaped and maintained by waves and tidal currents.

To better understand the nature and magnitude of hydraulic forces at work on the San Francisco sand bar and to ascertain the effects on the marine environment of disposing of dredged material at the chosen site, the following recommendations are offered.

(A) A search and review of literature concerned with submerged banks and the effects of disposal of material on sand bars.

(B) Based on the drogue path measurements, current observations, meterological and sea-state data, etc., attempt to determine the magnitude of hydraulic forces resulting from local currents and wave action. The force determinations should be related directly to the underwater topography of the Bar, navigation channels and shoreline.

(C) Ascertain the history of the configurations of San Francisco Bar and navigation channels, dredging quantities, etc., as related to past published tidal current precitions, hindcast data from Wave Station No. 3, Bar sediment sample characteristics and other oceanographic information.

(D) Refine disposal site tidal current measurements versus published tidal current (Golden Gate) correlation studies to develop prediction equations for estimating conditions at the Bar throughout the year.

(E) Measure at San Francisco Bar the nature and amount of material held in suspension by turbulent energy.

(F) Measure, at several other locations on the Bar and vicinity, the velocity gradient and direction of current flow.

(G) Attempt to develop dimensionless ratios to better describe the flow characteristics at and near San Francisco Bar.

This technique might provide a feasible means of correlating similar prototype phenomena and model studies without restriction to scale, magnitude of flow, or fluid properties.

SECTION 7

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APPENDIX - A

TABLES OF CHARACTERISTICS
OF DROGUE PATH

San Francisco Sand Bar

TABLE I-A

CHARACTERISTICS OF DROGUE PATH

(June 25-26, 1971)

Time	Drogue Path		Wind		Sea State		Remarks
	Velocity (Knots)	Direction (~~Mag Deg~~)	Velocity (mph)	Direction (Mag. Deg.)	Wave Height (feet)	Direction (Mag. Deg.)	(Time relative to High tide at Golden Gate)
June 25 22:30			3	170	1	230	Drogue released (HL + 2:30)
	0.38	NE					
June 25 23:30			3	230	1	230	(HH - 2:24)
	1.0	ENE					
June 26 00:30			3	230	1	230	(HH - 1:[illegible])
	0.63	ENE					
2:15			3	230	1	230	(HH + 0:24)
	0.75	SE					
2:55			3	230	1	230	(HH + 1:01)
	0.82	S					
3:35			3	230	1	230	(HH + 1:41)
	1.3	SSW					
4:30			2	230	1	230	(HH + 2:36)
	1.7	SSW					

Oceanographic Season ~ Upwelling

Depth of Drogue = 15 feet

TABLE I-A

CHARACTERISTICS OF DROGUE PATH

(June 25-26, [illegible])

Time	Drogue Path		Wind		Sea State		Remarks
	Velocity (Knots)	Direction (Mag. Deg.)	Velocity (mph)	Direction (Mag. Deg.)	Wave Height (feet)	Direction (Mag. Deg)	(Time Relative to High & Low at Golden Gate)
5:30			2	230	1	230	[HH+3:36] or [LL-3:24]
	1.3	SSW					
6:30			2	230	1	230	[LL-2:24]
	0.60	SSW					
7:30			5	240	1	230	[LL-1:24]
	1.3	SW					
8:30			5	240	1	230	[LL-0:24]
	0.33	N					
9:30			4	240	1	230	[LL+0:36]
	0.58	W					
10:30			4	220	1	230	[LL+1:36]
	1.0	NW					
11:30			CALM		1	230	[LL+2:36]
	1.6	N					

Oceanographic Season ~ Upwelling

Depth of Drogue = 15 feet

TABLE I-A

CHARACTERISTICS OF DROGUE PATH

(June 25-23 1971)

Time	Drogue Path		Wind		Sea State		Remarks
	Velocity (Knots)	Direction ~~(Mag Deg)~~	Velocity (mph)	Direction (Mag Deg)	Wave Height (feet)	Direction (Mag. Deg)	(Time Relative to High and Low at Golden Gate)
12:30			CALM		1	[illegible]	[LH + 2:30] or [LH - 3:42]
	1.3	N					
13:30			CALM		1	[illegible]	[LH - 2:42]
	1.1	NE					
14:30			CALM			27?	[LH - 1:42]
	[illegible]	N					
15:30			2	270	1	270	[LH - 0:34]
	1.2	NE					
16:30			CALM		1	270	[LH + 0:15]
	0.17	S					
17:30			CALM		1	270	[LH + 1:18]
	0.77	NNE					
18:30			6	270	1	270	[LH + 2:18]
	0.17	WNW					

Oceanographic Season ~ Upwelling

Depth of Drogue = 5 feet

TABLE I-A

CHARACTERISTICS OF DROGUE PATH

([illegible])

Time	Drogue Path Velocity (Knots)	Drogue Path Direction	Wind Velocity (mph)	Wind Direction (Mag. Deg.)	Sea State Wave Height (feet)	Sea State Direction (Mag. Deg.)	Remarks (Time Relative to High & Low at Golden Gate)
19:30			8	270	2	[illegible]	[HL - 1:24]
	0.37	SSW					
20:30			8	270	2	270	[HL - 0:24]
	0.43	SW					
[illegible]			7	270	2	270	[HL + 0:36]
	0.18	WSW					
June 26 22:30			7	270	2	270	End of test [HL + 1:36]

Oceanographic Season ~ Upwelling

Depth of Drogue = 15 feet

TABLE [illegible]-A

CHARACTERISTICS OF DROGUE PATH

(November 5-7, 1971)

Time	Drogue Path: Velocity (Knots)	Drogue Path: Direction (Mag. Deg.)	Wind: Velocity (mph)	Wind: Direction (Mag. Deg.)	Sea State: Wave Height (feet)	Sea State: Direction (Mag. Deg.)	Remarks [Time Relative to High & Low at Golden Gate]
November 5 23:00			3	030	1	290	Start of Test [LL + 3:24]
	0.92	NE					
November 6 0:00			3	030	1	290	[LH - 2:54]
	1.3	NE					
1:00			3	010	1	280	[LH - 1:54]
	1.5	NE					
2:00			2	010	1	270	[LH - 0:54]
	0.88	ESE					
3:00			2	010	1	270	[LH + 0:06]
	0.47	NNE					
4:00			1	010	1	270	[LH + 1:06]
	0.63	SSW					
5:00			1	010	2	270	[LH + 2:06] [HL - 2:00]
	1.6	WSW					

Oceanographic Season ~ Oceanic

Depth of Drogue = 15 feet

1 of 7

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TABLE 5-A

CHARACTERISTICS OF DROGUE PATH

(November 5-7 1971)

Δt	Time	Drogue Path		Wind		Sea State		Remarks
		Velocity (Knots)	Direction (Mag. Deg.)	Velocity (mph)	Direction (Mag. Deg.)	Wave Height (feet)	Direction (Mag. Deg.)	[Time Relative to High & Low at Golden Gate]
360	6:00			2	360	2	270	[HL − 1:00]
50		2.2	SSW	2	360	2	270	Maximum ebb at Golden Gate [HL − 0:35]
410	6:50			2	360	2	270	[HL − 0:10]
70		1.2						
480	8:00			3	010	1	270	[HL + 1:00]
60		0						
5.40	9:00			3	010	1	270	[HL + 2:00]
60		0.30	SE					
1.00	10:00			2	010	1	270	[HH − 3:06]
60		0.33	NNW					
6.60	11:00			3	0	1	270	[HH − 2:06]
60		1.0	NE					
720	12:00			3	360	1	270	[HH − 1:06]
60		0.83	ENE					

Oceanographic Season ~ Oceanic

Depth of Drogue = 15 feet

TABLE 2-A

CHARACTERISTICS OF DROGUE PATH

Δt	Time	Drogue Path Velocity (Knots)	Drogue Path Direction (Mag. Deg.)	Wind Velocity (mph)	Wind Direction (Mag. Deg.)	Sea State Wave Height (feet)	Sea State Direction (Mag. Deg.)	Remarks [Time Relative to High & Low at Golden Gate]
780	13:00			4	340	2	270	[HH - 0:06]
110		0.14	NE					
3090	14:50			6	340	2	280	[HH + 1:44]
770		0.17	NW					
[illegible]	16:00			5	320	2	280	[HH + 2:54]
60		2.9	SSE	4.5	325	2	[illegible]	[HH + 3:24]
1120	17:00			4	330	2	280	[HH + 3:54] or [LL - 3:00]
60		1.5	SSW					
1080	18:00			5	330	2	270	[LL - 2:30]
60		0.83	SW					
1140	19:00			5	330	2	270	[LL - 1:30]
60		1.3	SSW					
[illegible]	20:00			4	350	2	270	[LL - 0:30]
60		0.60	WNW					

Oceanographic Season ~ Oceanic

Depth of Drogue = 30 ft

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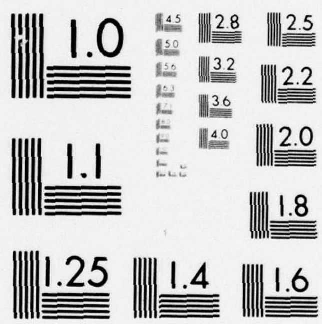

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TABLE -A

CHARACTERISTICS OF DROGUE PATH

(November 5-7, 1971)

Δt	Time	Drogue Path Velocity (Knots)	Drogue Path Direction ~~(Mag. Deg.)~~	Wind Velocity (mph)	Wind Direction (Mag. Deg.)	Sea State Wave Height (feet)	Sea State Direction (Mag. Deg)	Remarks [Time Relative to High & Low of Golden Gate]
1260	21:00			4	350	2	270	[LL+0:30]
60		0.67	SW					
1320	22:00			3	360	1	270	[LL+1:30]
60		0.37	WNW					
1380	23:00			2	360	1	270	[LL+2:30]
60		0.33	NW					
1440 0	November 7 0:00			2	350	1	270	
60		0.67	NW					
60	1:00			3	350	2	270	
60		0.27	NNW					
120	2:00			4	340	2	280	
60		0.83	N					
180	3:00			2	340	2	290	
60		0.53	N					

Oceanographic Season ~ Oceanic

Depth of Drogue = [illegible] feet

TABLE 2-A

CHARACTERISTICS OF DROGUE PATH

(November 5-7, 197[illegible])

dt	Time	Drogue Path Velocity (Knots)	Drogue Path Direction (Mag. Deg.)	Wind Velocity (mph)	Wind Direction (Mag. Deg.)	Sea State Wave Height (feet)	Sea State Direction (Mag. Deg.)	Remarks [Time Relative to High & Low at Golden Gate]
240	4:00			3	340	2	270	[LH + 0:06]
20		0.58	NNE					
300	5:00			5	[illegible]	2	270	[LH + 1:06]
30		0.20	SE					
[illegible]	6:00			6	[illegible]	2	270	[LH + 2:06]
0		0.13	SE					
420	7:00			5	320	2	270	[HL - 1:06]
0		0.47	SW					
480	8:00			6	320	2	270	[HL - 0:06]
0		0.50	SSW					
540	9:00			6	320	2	270	[HL + 0:54]
60		0.97	ESE					
600	10:00			5	330	2	270	[HL + 1:54]
60		0.30	SE					

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Oceanographic Season ~ Oceanic

5a#

Depth of Drogue = 15[illegible] ft

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TABLE 2-A

CHARACTERISTICS OF DROGUE PATH

(November 5th, 1971)

Δt	Time	Drogue Path Velocity (Knots)	Drogue Path Direction (Mag. Deg.)	Wind Velocity (mph)	Wind Direction (Mag. Deg.)	Sea State Wave Height (feet)	Sea State Direction (Mag. Deg.)	Remarks [Time Relative to High & Low at Golden Gate]
660	11:00			6	320	2	270	[HH + 3:00]
60		0.33	E					
720	12:00			6	320	2	270	[HH + 2:00]
70		0.31	N					
[illegible]	13:10			5	320	2	270	[HH + 0:50]
50		0.80	SW					
840	14:00			4	320	3	280	[HH + 0:00]
60		0.80	SW					
900	15:00			7	330	3	280	[HH + 1:00]
60		0.33	ESE					
960	16:00			8	330	3	280	[HH + 2:00]
60		0.87	SSE					
1020	17:00			10	320	4	270	[HH + 3:00]
210		0.47	S					

Oceanographic Season ~ Oceanic

Depth of Drogue = 15 feet

TABLE 6-A

CHARACTERISTICS OF DROGUE PATH

(November 5-7, 19[illegible])

dt	Time	Drogue Path Velocity (Knots)	Drogue Path Direction (Mag. Deg.)	Wind Velocity (mph)	Wind Direction (Mag. Deg.)	Sea State Wave Height (feet)	Sea State Direction (Mag. Deg.)	Remarks [Time Relative to High & Low at Golden Gate]
1230	20:30							[LL-1:00]
30		2.1	SSW	15 [illegible]	320	6 (sw)	270	Strong Ebb at Golden Gate [LL-0:45] Passing
1260	21:00			18	330	6	270	[LL-0:30]
60		0.25	E					
1320	22:00							End of Test [LL+0:30]

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Oceanographic Season ~ Oceanic

Depth of Drogue = 5 [illegible]

TABLE 3-A

CHARACTERISTICS OF DROGUE PATH

(February 1-3, 1972)

Δt	Time	Drogue Path Velocity (knots)	Drogue Path Direction	Wind Velocity (mph)	Wind Direction (Mag. Deg.)	Sea State Wave Height (feet)	Sea State Direction (Mag. Deg)	Remarks [Time Relative to High or Low at Golden Gate]
	February 11:40			9	045	1-2	045	Drogue Released [HH -0:49]
20		1.2	ENE					
	12:00			9	045	1-2	045	[HH -0:29]
65		0.[illegible]	ESE					
	13:[illegible]5			9	045			[HH +0:36]
55		0.82	SSE					
	14:00			9	045			[HH +1:31]
30		1.0	SSW					
	14:30			10	045	1-2		[HH +2:01]
90		0.56	SW					
	16:00			5	045			[HH+3:31] or [LL-2:56]
60		0.78	SSW					
	17:00			4	045	CALM		[LL-1:56]
60		0.60	SW					

Oceanographic Season ~ Davidson

Depth of Drogue = 15 feet

TABLE 5-4 (cont...)

CHARACTERISTICS OF DROGUE PATH

([illegible])

ct	Time	Drogue Path Velocity (Knots)	Drogue Path Direction (Mag. Deg.)	Wind Velocity (mph)	Wind Direction (Mag. Deg.)	Sea State Wave Height (feet)	Sea State Direction (Mag. Deg.)	Remarks
	01:00			3	0	CALM		[HH - 0:48]
60		0.30	NNW					
	02:00			5	045	CALM		[HH + 0:12]
60		0	Almost stationary					
	03:00			5	045	CALM		[HH + 1:12]
60		0.75	S					
	04:00			7	045	CALM		[HH + 2:12]
60		0.43	SSW					
	05:00			10	045	1-2		[HL - 2:10]
60		0.67	SSW					
	06:00							[HL - 1:10]
60		0.37	SW					
	07:00			14	090	3		[HL - 0:10]
60		1.0	SW					

Oceanographic Season ~ Davidson

Depth of Drogue = [illegible]

TABLE 3-4 (continued) BEST AVAILABLE COPY

CHARACTERISTICS OF DROGUE PATH

(February 1-2, 1972)

Δt	Time	Drogue Path Velocity (Knots)	Drogue Path Direction (Mag. Deg.)	Wind Velocity (mph)	Wind Direction (Mag. Deg.)	Sea State Wave Height (feet)	Sea State Direction (Mag. Deg.)	Remarks [Time Relative to High & Low at Pilot ...]
	18:00			CALM				[LL - 0:56]
60		0.47	SSW					
	19:00			CALM				[LL + 0:04]
60		0.60	W					
	20:00			5	045			[LL + 1:04]
60		0.45	NE					
	21:00							[LL + 2:04]
60		0.30	SE					
	22:00			10	270			[LL + 3:04]
60		0.47	NNE					
	23:00			17	270			[HH - 2:48]
60		0.33	NE					
	February 2 00:00			5	0	CALM		[HH - 1:48]
60		0.50	NNE					

Oceanographic Season ~ Davidson

Depth of Drogue = 15 feet

TABLE 3-A

CHARACTERISTICS OF DROGUE PATH

(February 1-2, 1972)

Time	Drogue Path		Wind		Sea State		Remarks
	Velocity (Knots)	Direction (Mag. Deg.)	Velocity (mph)	Direction (Mag. Deg.)	Wave Height (feet)	Direction (Mag. Deg.)	[Time Relative to High & Low at Golden Gate]
08:00			15	090	3		[HL + 0:50]
	0.47	WNW					
09:00				090			[HL + 1:50]
	0.47	WNW					
10:00				135			[HL + 2:50] or [LH - 3:12]
	0.22	NNE					
11:00			11	135	3		[LH - 2:12]
	0.86	NW					
12:10							[LH - 1:02]
	0.37	W					
13:10			14	0	2	180	[LH - 0:02]
	0.34	NNW					
14:00							[LH + 0:48]
	0.50	N					

Oceanographic Season ~ Davidson

Depth of Drogue = 15 feet

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TABLE 3-A

CHARACTERISTICS OF DROGUE PATH

(February 1-2, 1972)

Δt	Time	Drogue Path Velocity (Knots)	Drogue Path Direction (Mag. Deg.)	Wind Velocity (mph)	Wind Direction (Mag. Deg.)	Sea State Wave Height (feet)	Sea State Direction (Mag. Deg.)	Remarks [Time Relative to High & Low at Golden Gate]
	15:00			19	090	4	270	[LH + 1:48]
60		0.63	NW					
	16:00			19	090	4	270	[LH+2:48] or [LL-3:32]
60		0.27	NNW					
	17:00			17	090	4	090	[LL - 2:32]
90		0.33	W					
	18:30			17	090	3	090	[LL - 0:52]
50		0.36	NNW					
	19:20			17-23	090	5-6	090	End of Test [LL-0:02]

Oceanographic Season ~ Davidson

Depth of Drogue = 5 feet

INCLOSURE 4

DIVER'S LOGS

SAN FRANCISCO BAR
DIVER DEBRIEFING

Benthic Sampling Area 250' Within Buoy #3 Main Ship Channel

Wind Direction West

Date 27 Sept 71

Velocity 0-5 mph

Time Start 0917

Sea State 1-2 foot swells

End 0933

Weather Sunny-Clear

Tidal Current Stage Slack @ 0836 and 1.2 Ebb @ 1024 for Golden Gate

Visibility and Turbidity (sight distance, material in suspension, etc.)

Depth	Surface	10 ft	30 ft	40 ft	50 ft	58 ft Bottom
Temp	59°	58°	55°	53°	52°	52°
Visibil.	15 ft.	15 ft	15 ft	15 ft	5 ft	0-1 ft

Turbulence (direction and strength of current, catenary and scope of line, etc.)
Current toward south at about 1/2 knot, little surge with bottom foot of water column turbid.

Bottom Conditions

Type of Sediment (clay, silt, sand, etc.)
Silty sand

Compaction of Sediment (penetration easy or difficult)
Top couple inches loose

Topography (smooth, ripple marks, any scour, etc.)
4" x 1/2" ripple marks with axis oriented NW-SE

Marine Life

Benthic (what kind, how many, moving or sessile, orientation)
None noted

Pelagic (what kind, how many, what size, what depth)
None noted

Organic Material (any layer of organic sediment, etc.)
Some shell fragments were on the bottom. The lower 10 feet of water column contained Liptopel. a fine white material.

Other Comments

1. Divers were Bob Hardy and Don Odenweller.
2. Divers could not see bottom when surge disturbed bottom foot of water column. Bottom was visible about 5% of time. Surge was fairly constant.
3. A sand sample in a plastic bag was obtained and sieved with #30 for benthic sample.

SAN FRANCISCO BAR
DIVER DEBRIEFING

Benthic Sampling Area 250' within Buoy #5 Main Ship Channel   Wind Direction West

Date 27 Sept 71   Velocity 0-5 mph

Time Start 1023   Sea State 1-2 foot swells 11 sec

End 1040   Weather Sunny-Clear

Tidal Current Stage 1.2 Ebb @ 1024 for Golden Gate

Visibility and Turbidity (sight distance, material in suspension, etc.)
0 feet at bottom without light, 4-5 feet at about 4 feet from bottom. Bottom one foot had high turbidity, never able to see bottom.

Turbulence (direction and strength of current, catenary and scope of line, etc.)
5 second eddy with 1½ foot horizontal back and forth water movement

Bottom Conditions

Type of Sediment (clay, silt, sand, etc.)
Fine silty sand

Compaction of Sediment (penetration easy or difficult)
Could push hand easily into top 1½" of sand, compacted below 1½". Sample was scratched out with fingers.

Topography (smooth, ripple marks, any scour, etc.)
6-8" x ½" ripple marks

Marine Life

Benthic (what kind, how many, moving or sessile, orientation)
1 Sand Dollar (Dendraster excentricus) felt in a 20 ft² area.

Pelagic (what kind, how many, what size, what depth)
None noted

Organic Material (any layer of organic sediment, etc.)
None noted

Other Comments

1. Divers were Doug Pirie and Cpt. Russ Flegal.
2. Divers never could see the bottom.
3. About ¼ ft³ sample was obtained using a plastic bag and sieved with #30 for benthic sample.

SAN FRANCISCO BAR
DIVER DEBRIEFING

Benthic Sampling Area 250' within Buoy #5 Main Ship Channel
Wind Direction West

Date 27 Sept 71
Velocity 0-5 mph

Time Start 1057
Sea State 1-2 foot swells

End 1118
Weather Sunny-Clear

Tidal Current Stage 1.2 Ebb @ 1024 for Golden Gate

Visibility and Turbidity (sight distance, material in suspension, etc.)
2-4 foot visibility near bottom

Turbulence (direction and strength of current, catenary and scope of line, etc.)
Minor surge

Bottom Conditions
Type of Sediment (clay, silt, sand, etc.)
About 1" soupy silty sand in some areas
Compaction of Sediment (penetration easy or difficult)
underlying material dense like clay
Topography (smooth, ripple marks, any scour, etc.)
4" x ½" ripple marks with axis oriented NW-SE

Marine Life
Benthic (what kind, how many, moving or sessile, orientation)
1 Slender Crab (Cancer gracilis)
2 Sand Dollars (Dendraster sp.)
1 Hermit Crab (Pagurus sp.)
Polychaete Wormtubes abundant
Pelagic (what kind, how many, what size, what depth)
None noted

Organic Material (any layer of organic sediment, etc.)
Moderate amount of drift debris along ridges of ripples.

Other Comments
1. Divers were Bob Hardy and Don Odenweller.
2. Divers covered an area to 100 feet from anchor toward Buoy #5.
3. Benthic samples above were collected.

SAN FRANCISCO BAR
DIVER DEBRIEFING

Benthic Sampling Area 3400 feet south of Buoy #4 Wind Direction West

Date 28 Sept 71 Velocity 0-5 mph

Time Start 0916 Sea State 1 foot swells

End 0938 Weather Sunny - Light Clouds

Tidal Current Stage Slack @ 0836 and 1.3 Ebb @ 1130 for Golden Gate

Visibility and Turbidity (sight distance, material in suspension, etc.)

Depth	Surface	10 ft	20 ft	30 ft	40 ft	45 ft bottom
Temp	57°	56°	54°	53°	51°	51°
Visibil.	10 ft	10 ft	10 ft	6 ft	6 ft	5-6 ft

Turbulence (direction and strength of current, catenary and scope of line, etc.)
Moderate surge about E-W, slight current

Bottom Conditions
Type of Sediment (clay, silt, sand, etc.)
Fine clean sand, easily stirred up
Compaction of Sediment (penetration easy or difficult)
Firmer than previous day
Topography (smooth, ripple marks, any scour, etc.)
4" x 1/2" ripples, patterns were broken with crossing patterns.

Marine Life
Benthic (what kind, how many, moving or sessile, orientation)
Sand Dollars (Dendraster sp.) about 1 per meter²
Hermit Crabs (Pagurus sp.) abundant
Several snail species
1 Sand Dab (Citharichthys)
Pelagic (what kind, how many, what size, what depth)
None noted

Organic Material (any layer of organic sediment, etc.)
Shell fragments and Liptoped in suspension

Other Comments
1. Divers were Bob Hardy and Don Odenweller.
2. Individual snail species were collected and a sand sample was obtained in a plastic bag and sieved with #30 for benthic sample.

by J. Sustar

SAN FRANCISCO BAR
DIVER DEBRIEFING

Benthic Sampling Area 3000 Feet South of Buoy #6 Wind Direction West

Date 28 Sept 71 Velocity 0-5 mph

Time Start 1005 Sea State 1 foot swells

End 1035 Weather Sunny - Light Clouds

Tidal Current Stage Slack @ 0836 and 1.3 Ebb @ 1130 at Golden Gate

Visibility and Turbidity (sight distance, material in suspension, etc.)
2-3 feet on the bottom and 10 feet or better above.

Turbulence (direction and strength of current, catenary and scope of line, etc.)
Surge light to medium, non-constant with horizontal movement about 2 feet, current parralle[l] to ripple marks.

Bottom Conditions
Type of Sediment (clay, silt, sand, etc.)
Light brown fine sand
Compaction of Sediment (penetration easy or difficult)
About 1" to 3" penetration with hand
Topography (smooth, ripple marks, any scour, etc.)
3-4" × 1/2" ripple marks

Marine Life
Benthic (what kind, how many, moving or sessile, orientation)
Sand Dollars (Dendraster excentricus) 1 to 14 per foot² with about 7 as average
3" Sand Dabs (Citharichthys) abundant - at least twenty seen
Pelagic (what kind, how many, what size, what depth)
None noted

Organic Material (any layer of organic sediment, etc.)
Some debris along ridges of ripple marks.

Other Comments
1. Divers were Doug Pirie and Cpt. Russ Flegal.
2. Sand Dollars were collected and a sand sample was obtained in a plastic bag and sieved with a #30 for benthic sample.

SAN FRANCISCO BAR
DIVER DEBRIEFING

Benthic Sampling Area 3000 Feet South of Buoy #6 Wind Direction West

Date 28 Sept 71 Velocity 0-5 mph

Time Start 1048 Sea State 1 foot swells

End 1104 Weather Sunny-Light Clouds

Tidal Current Stage 1.3 Ebb @ 1130 for Golden Gate

Visibility and Turbidity (sight distance, material in suspension, etc.)
2 to 3 feet near the bottom

Turbulence (direction and strength of current, catenary and scope of line, etc.)
Surge moderate

Bottom Conditions
Type of Sediment (clay, silt, sand, etc.)
Fine sand
Compaction of Sediment (penetration easy or difficult)
Firm
Topography (smooth, ripple marks, any scour, etc.)

Marine Life
Benthic (what kind, how many, moving or sessile, orientation)
2 Market Crabs (Cancer magister)
1 Crab (Cancer productus)
1 Sand Dab (Citharichthys)
Sand Dollars (Dendraster excentricus) abundant
Pelagic (what kind, how many, what size, what depth)

None noted

Organic Material (any layer of organic sediment, etc.)
Some debris on ridges of ripple marks

Other Comments
1. Divers were Bob Hardy and Don Odenweller
2. Crab species were obtained (for Fish and Game Dept.)

by J. Suster

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SAN FRANCISCO BAR
DIVER DEBRIEFING

Benthic Sampling Area 3000 Feet South of Buoy #8 Wind Direction South-West

Date 28 Sept 71 Velocity 0-5 mph

Time Start 1131 Sea State 1 foot swells

End 1152 Weather Sunny Light Clouds

Tidal Current Stage 1.3 Ebb @ 1130 for Golden Gate

Visibility and Turbidity (sight distance, material in suspension, etc.)

Depth	Surface	10 ft.	20 ft.	30 ft.	40 ft.	50 ft.
Temp.	58°	56°	54°	53°	52°	52°
Visibil.	10 ft	10 ft	10 ft.	10 ft.	10 ft.	1-2 ft

Turbulence (direction and strength of current, catenary and scope of line, etc.)
Surge moderate with no currents noted

Bottom Conditions
Type of Sediment (clay, silt, sand, etc.)
Coarser sand
Compaction of Sediment (penetration easy or difficult)
Pencil penetration about 6 inches, fairly compact
Topography (smooth, ripple marks, any scour, etc.)
6"x 3/4" ripple marks with some areas 12"x 2" and some with none.

Marine Life
Benthic (what kind, how many, moving or sessile, orientation)
Sand Dollars (Dendraster excentricus) sparse
Hermit Crabs (Pagurus sp.) sparse
Sand Dabs (Citharichthys) sparse
Wormtubes, sparse and large and small snails
Pelagic (what kind, how many, what size, what depth)
None noted

Organic Material (any layer of organic sediment, etc.)
Leptopel in entire water column, especially heavy in the lower 3 feet. One piece of drifting kelp.

Other Comments
1. Divers were Bob Hardy and Don Odenweller.
2. Sand Dollars and Snails were collected and a sand sample was obtained in a plastic bag and sieved with #30 for benthic sample.

SAN FRANCISCO BAR
DIVER DEBRIEFING

Benthic Sampling Area 3000 Feet South of Buoy #8 Wind Direction South-West

Date 28 Sept 71 Velocity 5-10 mph

Time Start 1210 Sea State 1-2 foot swells

End 1232 Weather Sunny - Light clouds

Tidal Current Stage 1.3 Ebb @ 1130 for Golden Gate

Visibility and Turbidity (sight distance, material in suspension, etc.)
without light, could see about 6 inches at bottom; with light, about 1-2 feet. Visibility decreased rapidly between 3 feet from bottom and the bottom

Turbulence (direction and strength of current, catenary and scope of line, etc.)
Non-constant surge 4 second

Bottom Conditions
Type of Sediment (clay, silt, sand, etc.)
Coarser sand
Compaction of Sediment (penetration easy or difficult)
About 4 inches of penetration with hand
Topography (smooth, ripple marks, any scour, etc.)
Larger ripples 12"x 3" with 4"x 3/4" ripples imposed.

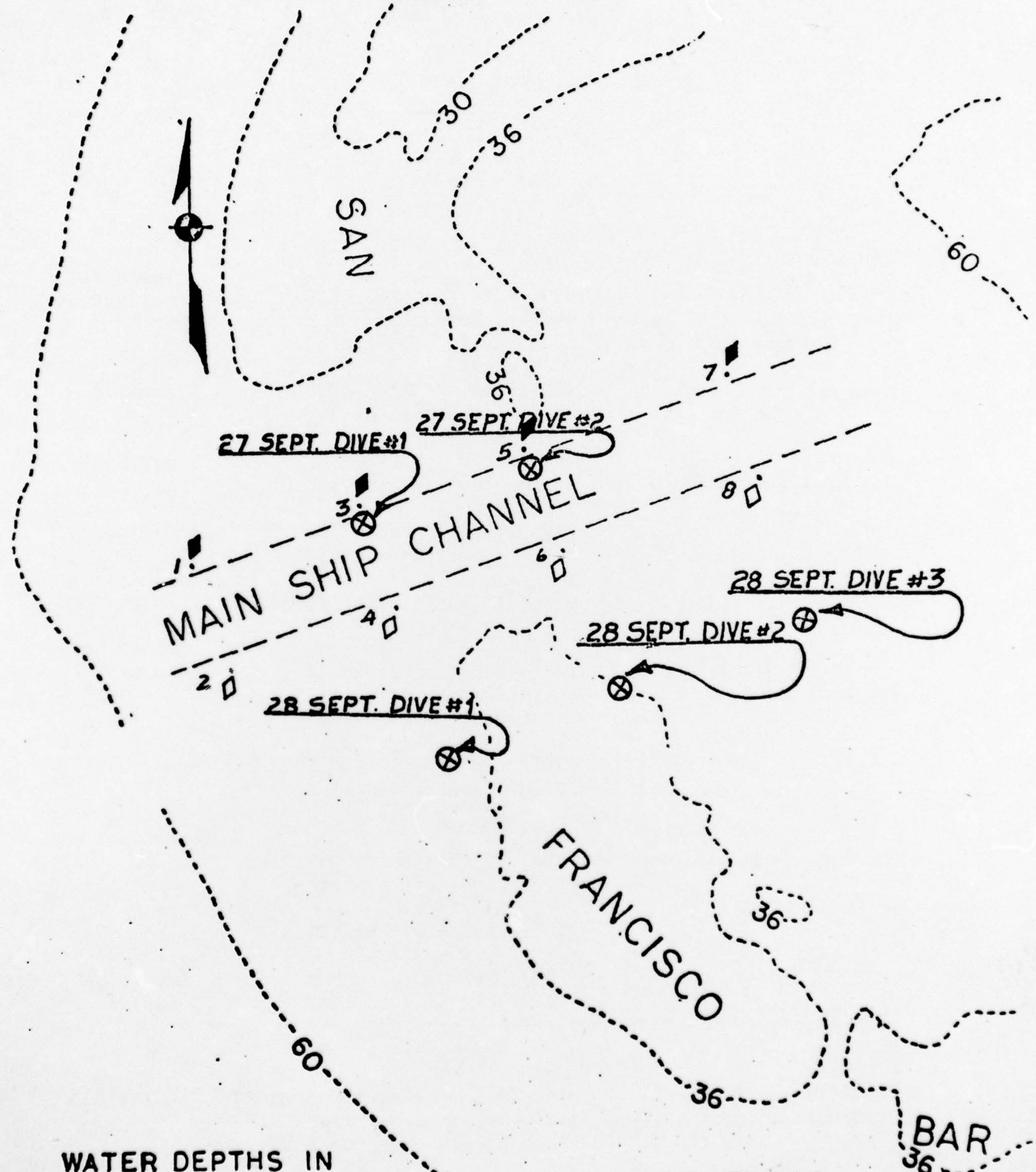
Marine Life
Benthic (what kind, how many, moving or sessile, orientation)
2 Spiny Sand Crabs (Blepharipoda occidentalis)
1 Market Crab (Cancer magister)
Few Sand Dollars (Dendraster excentricus)
Snails
Pelagic (what kind, how many, what size, what depth)

None noted

Organic Material (any layer of organic sediment, etc.)
Wood particles and debris including 4"x1" rounded, well seasoned wood 1 every four to five feet. Lots of shell and crab fragments, and drifting green sea grass.

Other Comments
1. Divers were Doug Pirie and Cpt. Russ Flagg

Jo Suntor



WATER DEPTHS IN FEET BELOW MEAN LOWER LOW WATER

DIVING LOCATIONS
SEPTEMBER 1971

SCALE IN NAUTICAL MILES

1 1/2 0 1

SAN FRANCISCO BAR DREDGE MONITORING
DIVING SUMMARY
8 February 1972

	Ron Ard	Doug Pirie	Russ Flegal	Rod Chisholm
1st Dives				
Station 1	0920-0938	0922-0927	0930-0948	0933-0947
	Set substations, yellow rock and rod; lost pan; observed bottom conditions; and obtain 3 liter sample.			
Station 2	0955-1015	1002-1014	-	-
	Set substations, yellow rock, rod and pan.			
Station 3	1024-1036	1021-1035	-	-
	Set substations, yellow rock and rod; and lost pan.			
Station 4	1050-1058	1051-1057	-	-
	Dives aborted			
	DREDGE RELEASE AT SECTION 1108 (+1 minute)			
2nd Dives				
Station 1	1228-1230	1227-1245	1234-1245	-
	Set white rock; lost pan; marked rod; and took two core samples from yellow rock.			
Station 4	1304-1306	1317-1326	1316-1326	-
	Set substations, white rock and rod.			
Station 3	-	1343-1355	1342-1354	
	Set white rock; marked rod; and took two core samples from yellow rock.			
	DREDGE RELEASE AT SECTION 1427			
3rd Dives				
Station 2	1457-1508	1458-1507	-	-
	Took two core samples from white rock; marked rod; and recovered rod and pan.			
Station 1	1511-1524	1511-1524	1515-1530	1515-1530
	Took two core samples from white rock; obtained 3 liter sample; and could not locate rod.			
Station 3	1544-1552	-	1545-1552	-
	Took one core sample and could not locate rod.			
Station 4	-	-	1558-1604	1559-1604
	Took one core sample; and marked and recovered rod.			